

U.S. Mines Bureau

Bulletin 60

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

HYDRAULIC MINE FILLING

ITS USE IN THE
PENNSYLVANIA ANTHRACITE FIELDS

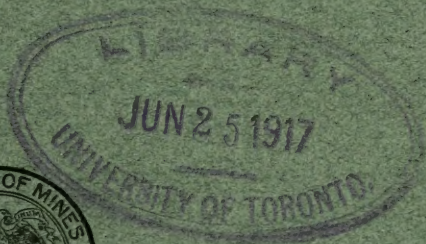
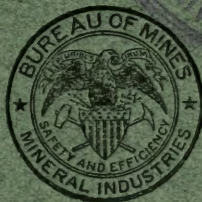
A PRELIMINARY REPORT

BY

CHARLES ENZIAN

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WASHINGTON
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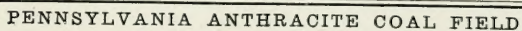
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Scale
10 0 10 20 Miles

After map of U. S. Geological Survey.



HYDRAULIC MINE FILLING; ITS USE IN THE PENNSYLVANIA ANTHRACITE FIELDS.

By CHARLES ENZIAN.

INTRODUCTORY STATEMENT.

This report is issued by the Bureau of Mines as one of a series dealing with methods of increasing safety and efficiency in mining operations. It is intended purely as a preliminary statement of the present development of hydraulic mine filling as conducted in the anthracite region of Pennsylvania. A discussion of different methods, their variations and modifications, as well as their probable extension as a result of amplified tests of the various roof-supporting materials, will be presented in a future bulletin.

The history of the development of the anthracite-mining industry, from the time when the Indian tribes in the Wyoming and Lackawanna Valleys first discovered the existence of "stone coal," on through subsequent events—the purchase of lands containing enormous deposits of coal for insignificant sums of money, the development of the first mine, the formation of the first company, the building of canals and railroads—up to the present time when the industry has become of such tremendous importance to the prosperity of north-eastern Pennsylvania and of the Nation itself, is intersprinkled with romance, tragedy, and pathos.

The great economic lessons to be learned from a study of mining operations in the anthracite region suggest to the person interested in the efficient utilization of natural resources the need of applying such methods as will make possible the conservation to posterity of this invaluable deposit of coal that has resulted from the operation of the processes of nature during probably hundreds of millions of years.

It is the opinion of many prominent mining men familiar with mining operations in the United States and abroad that under certain conditions the most practical way of preventing loss of unmined coal in pillars and of protecting surface property from damage by subsidence is by filling the workings with refuse material. This bulletin aims to present a general discussion of hydraulic mine filling, its origin, development, and practicability in anthracite mining.

The fundamental object of this bulletin is to enlist the thoughtful cooperation of the entire mining fraternity in such methods of mining as will accomplish the greatest good, by avoiding stream pollution, by conserving natural resources, and by reducing mining losses to a minimum. The value of mine filling as a roof support, whether for surface protection, reinforcement of pillars, or reclamation of pillars, can hardly be placed too highly. In fact, under certain geological conditions, particularly the occurrence of water-bearing strata over the coal, the maximum winning of coal practically can not be economically attained without the use of mine filling.

TERMS USED.

In this discussion the author has deviated slightly from common usage in his choice of terms, believing some of those that have been used in connection with the process of filling mine workings by hydraulic methods to be neither suitable nor descriptive. Heretofore the process has been termed and even at present is known in the Pennsylvania anthracite region as "slushing," "flushing," and "silting." As a result of various suggestions from men of long experience in this work, the name "hydraulic mine filling" (filling the mine with materials transported by water) was adopted for use in this bulletin.

The expression "physical conditions," as applied to mine workings, refers particularly to the manner of mining, whether uniform or irregular; the size of openings and the size and shape of pillars; the extent of roof and coal falls, and the general accessibility of the mine workings. The expression "geological conditions" relates particularly to the general dip of the coal bed and to local variations of dip or interruptions of continuity from folds or faults.

The term "pitch" as used in this report signifies both the inclination or dip of a coal bed, and hence the inclination of the workings in the bed, and, as in the expression "pitch workings," an inclination of more than a certain number of degrees.

A well-defined distinction exists between the terms "mine loss," "breaker loss," and "coal loss." Mine loss refers to such low-grade coal as is rejected by the miner at his working face because in his opinion it will not meet with the requirements of the rigid inspection in the breaker when his coal is dumped from the cars into the chute leading to the first picking chutes, screens, or shaker bars. Breaker loss refers to such low-grade coal as is rejected during the process of breaker preparation. Coal loss embraces both the material rejected by the miner at the face and by the inspectors at the breaker, and that which is lost, mostly by breakage, in transportation, storage, and marketing.

ACKNOWLEDGMENTS.

The author hereby acknowledges the helpful cooperation of the coal companies in the anthracite region and of their officials who have extended so many facilities for the collection of valuable data. He also acknowledges the inspiration drawn from the work of Dr. J. A. Holmes, Director of the Bureau of Mines, whose earnest efforts to promote scientific investigations in mining have inspired many others; the helpful criticism of G. S. Rice, chief mining engineer of the bureau, whose observations on European methods were of aid in shaping the text; and the valuable assistance of A. H. Fay and Samuel Sanford, engineers of the bureau, in the compilation of the data presented.

GROWTH OF THE ANTHRACITE INDUSTRY.

William Griffith^a compiled a chronology of the anthracite-mining industry with great care, giving the principal events in its history from the earliest times up to and including 1908. It is particularly interesting to note that the shipping of anthracite coal began in 1776. The chronology states further:

In 1792 Col. Weiss and others formed the Lehigh Coal Mine Co., the first of its kind in the United States. In 1803 this company succeeded in getting two ark loads, about 30 tons, to market at Philadelphia, but no purchasers could be found. City authorities, as an experiment, tried to burn it beneath the boiler at the water works, but "it only served to put the fire out," and the remainder of the shipment was broken up and distributed over the sidewalks of the vicinity in place of gravel.

In 1808 Judge Jesse Fell recorded the fact that he had tried the experiment "of burning the common stone coal of the valley in a grate in a common fireplace in my house and find it will answer the purpose of fuel, making a clearer and better fire at less expense than burning wood in the common way."

The Pennsylvania anthracite region is geographically divided into four sections, generally known as the northern, eastern middle, western middle, and southern fields. The coal shipped from the various fields is known under trade names as follows: That from the northern as "Wyoming," that from the eastern middle and the eastern southern as "Lehigh," and that from the western middle and the western southern as "Schuylkill." The quantity^b of coal shipped from the various fields from 1820, when the first shipment of commercial importance (365 tons) was made from the Lehigh region, to January 1, 1912, has been as follows: Wyoming region, 959,347.466 tons; Schuylkill region, 576,745.104 tons; Lehigh region, 283,258.115 tons; aggre-

^a 1908 Rept. of the Dept. of Mines of Pennsylvania, 1909, Pt. I, pp. xxx-xxxv; reprinted in the Scranton Truth, issue of Feb. 24, 1908.

^b Parker, E. W., Mineral Resources, U. S., 1911; U. S. Geol. Survey, 1911, pp. 11-12.

gating 1,819,350,685 tons. As will be noted, the respective percentages of production of the three regions are 53, 32, and 15. The estimated value of the 80,732,013 long tons of anthracite coal shipped during 1911 was \$174,852,843. The entire quantity of anthracite coal thus far shipped to market from these three regions, if loaded on one train of coal cars, would require a train long enough to encircle the globe 11 times or it would represent a prism having a base 1 mile square and a height of 2,600 feet.

HISTORICAL REVIEW OF HYDRAULIC MINE FILLING.

The first instance of the application of hydraulic mine filling is reported to have been at a mine in the Schuylkill region in 1884 for the purpose of extinguishing a mine fire at an intermediate level on the main haulage slope. After the failure of many attempts to extinguish the fire by flooding the slope with large quantities of water sent down intermittently, the superintendent conceived the idea of running the fine culm and coal dirt from the culm bank into this water, with the hope of filling up and thereby sealing the affected portion of the slope.

About 1886 and 1887 hydraulic mine filling was introduced in the Lehigh and Schuylkill regions for the purpose of sealing off mine fires, arresting squeezes, and supporting the surface. During the latter part of 1890 and the early part of 1891 hydraulic mine filling on a more systematic and economical basis was introduced in the northern field.^a This installation was practically the first in which the filling material was conveyed to the mine workings through a pipe line laid from the breaker down the shaft and into the worked-out chambers. Shortly after this time a party of foreign engineers visited Pennsylvania. The members studied hydraulic mine filling as then practiced and after returning to Europe proceeded to adopt it. The method has now become highly developed in several European coal fields and has been described repeatedly in foreign publications.

In the mines throughout the northern anthracite field of Pennsylvania hydraulic mine filling has become a part of the regular scheme of mining operations, being used particularly in areas in which inaccessible mine fires exist, or where squeezes are active, or where there is danger from surface subsidence, or where it is desired to reclaim coal pillars. Mine filling was used about 1895 to retard mine fires at the Summit Hill^b and the Sioux collieries. An early (1887) example of hydraulic mine filling for surface support is that at the

^a Davies, J. B., 1897, Rept. of the Bureau of Mines, Dept. of Internal Affairs of Pennsylvania, 1898, pp. XXXV-LI; also Pa. Anth. Operators' Assn., February, 1898.

^b Stock, H. H., Sealing off Summit Hill mine fire; Mines and Minerals, Aug., 1909, pp. 1-5.

Kohinoor colliery, Shenandoah, Pa. In many mines throughout the entire anthracite region the reclamation of pillars is possible to a great extent because of former hydraulic filling.

The development of hydraulic mine filling in the anthracite mines was due in a marked degree to a serious problem confronting the operators—the proper disposition of the principal by-product resulting from the mining and the preparation of anthracite coal for the market. This by-product, generally called “culm,” consists of that part of the breaker product that passes through the screens over which the smallest size of commercial product passes.

APPLICATIONS OF HYDRAULIC MINE FILLING.

The filling of mine workings may be said in general to be the outcome of a desire to get more merchantable coal from a given area of ground. Like many other useful innovations, the process originated in an attempt to meet a grave emergency. The principal applications of hydraulic filling are described below.

EXTINGUISHING MINE FIRES.

The hydraulic method of mine filling is reported to have been employed as early as 1884 to extinguish a serious mine fire. The fire originated in one of the deep lifts or levels of a haulage slope in an anthracite mine, and after raging for several days was making its way among timbers and fallen coal to higher levels, where its extinguishment by methods then in use would have been very expensive and might have permanently ruined the mine. Water had been turned down the slope in flooding quantities at regular intervals with the hope of checking and extinguishing the flames. After considerable time had been lost in this manner with no apparent improvement or success, the idea of sending down culm mixed with water was conceived and applied. The intermittent flooding with water did not fill up crevices and openings in the débris and fallen coal and rock, but after culm had been flushed into the lower section of the slope for some time it filled the interstices of the fallen material, thus excluding the air and soon bringing the fire under control. Several years later hydraulic mine filling began to be generally employed for the purpose of extinguishing or smothering isolated mine fires, either by the direct filling of the workings affected or by the construction of temporary or permanent barriers. This practice is now common and is termed “sealing off a fire by the hydraulic-filling method.”

The successful application of the various methods of extinguishing mine fires with large quantities of water, whether in steady streams, in pulsating streams, or in flooding quantities, or with mixtures of

water and refuse material, depends to a great extent on the geological structure of the coal bed and the situation of the mine workings and the mine in relation to the available supply of water and "filler." At a mine operated at a considerable distance from available filling material it may be necessary to lay long pipe lines to a convenient surface location and to furnish expensive motive power.

The filler, after having been properly prepared, must be sent into the mine through a suitable opening. At many mines only bore holes are practicable. For such mines the best location of the bore hole is determined from examination of maps or other available data; sometimes from the best recollection of old-time miners. The latter necessity arises, in the case of old workings, because the maps of such workings, made at a time when the mining engineer or surveyor was seldom considered necessary, are incomplete or unsatisfactory.

The filler, after passing down the bore hole, flows unconfined into the inaccessible workings, causing blockages among the caves, and forming finally an effective permanent sealing pillar. In some mines this requires weeks of filling, and in other mines blockage is complete in less than a day. Under more favorable conditions, as in a mine where a fire may be in progress in "live" or producing workings and where the filler can be transported to and deposited at predetermined points, the burning section is isolated so that the fire can not spread to adjacent workings, and the fire is allowed to burn to extinction within the sealed area.

The fire may be smothered by depositing filler in such a manner as to confine completely the burning district within well-defined bounds by filling the openings so as to exclude air and thus cause such a deficiency of oxygen in the atmosphere that it will not support combustion. This method was used in a Wilkes-Barre mine in which a fire had been in progress for some years. The burning area was on an anticline and the fire could not be extinguished by the usual methods of flooding. Bulkheads were constructed in the mine workings at lower points, and the open space inside of the bulkheads was filled by means of pipes which were run either above the bulkheads, along crosscuts and traveling ways, or through the bulkheads, so that they discharged some distance above the bulkheads, to insure absolutely air-tight blockage at the bulkheads.

ARRESTING MINE SQUEEZES.

The use of hydraulic filling for arresting mine squeezes was adopted many years ago shortly after its introduction for the purpose of extinguishing mine fires. In mine squeezes the attending phenomena are probably as menacing as those of mine fires. The

crunching and roaring noises of distant caves are alarming even to the most experienced miner and terrify those who live near or over the workings affected.

The first observed indications of a squeeze are a slight chipping of pillars. The usual cause of a squeeze is an excessive extraction of coal, too little being left in pillars. The quantity of coal usually extracted is determined almost entirely by local conditions, the physical character of the coal, its structure, the depth at which the bed lies, the thickness of the bed, and the method by which it is worked. An excellent discussion of the proper percentage of coal to be removed under stated conditions has been given by Bunting.^a

When a squeeze has started the retarding of its progress is very difficult, especially if the bed is inclined. Pillars in inclined beds are crushed by the vertical pressure of overburden, and in addition are subjected to a side thrust through the settling of the roof. To stop a squeeze, timber is often placed in every conceivable form and position, as battalions of props and cogs, but when timber is ineffective, retreat is made to a presumably safe distance, and part of the unaffected territory ahead of the line of danger has to be sacrificed. Bulkheads are erected and filler is deposited as far as possible toward the advance of the squeeze. It is highly important that the greatest possible quantity of filler of the best quality be deposited in the shortest possible time. In emergencies like these "a minute in time may save the mine."

SUPPORTING THE SURFACE.

Hydraulic mine filling has played an important part and been highly effective in the prevention of surface subsidence. The first recorded application dates back to 1886, and the published account substantiates the assertion that hydraulic filling effectively avoided the settling of a large part of a mining town. In this instance the pillars in a moderately worked section of the mine where the dip was steep began to "run" and caused a slight subsidence of the surface. In many mines where coal has been removed somewhat excessively under valuable surface land and structures, the openings underneath are either partly filled with hydraulic filler, or "stows" of mine rock are built and the hydraulic filler is flushed in to fill the voids or interstices in the stows. In the Pennsylvania anthracite fields work of this kind is undertaken by either the surface owners or the operators, according to the provisions in the deed or lease conveying the surface. Usually the operators perform the work, the expense being borne by them or by the surface owner, as stipulated.

^a Bunting, Douglas. Chamber pillars in deep anthracite mines: Trans. Am. Inst. Min. Eng., vol. 42, 1911, pp. 236-245.

RECLAIMING PILLARS AND INCREASING YIELD.

A use of hydraulic filling that is practical and at the same time directly profitable was devised for the double purpose of disposing of refuse and of reclaiming pillars. The disposal of refuse, involving possible stream pollution, is discussed below; the reclamation of pillars pertains directly to the economical extraction of all the coal in favorable sections and also to the unfavorable geologic conditions due to overlying water-bearing strata. This use was introduced in the northern anthracite field in 1891.^a By means of systematic filling the pillars were made available for extraction by the splitting, blocking, or slabbing methods, as the conditions required; later by refilling the rooms (chambers) the maximum yield of coal was obtained.

DISPOSING OF SPOIL BANKS.

Although hydraulic mine filling originated as a matter of necessity, it was developed to serve many different purposes in the anthracite industry. The huge unsightly spoil banks, the silent evidences of the waste caused by an exacting market, began to disappear and now are the exception rather than the rule.

The primary utility of hydraulic mine filling—disposal of waste—was anticipated, and from the development and expansion of the system a most commendable change in the appearance of the landscape about the collieries is being brought about. The spoil banks are being rehandled, the marketable sizes of the coal are being reclaimed, and the unmarketable product called culm is being hydraulicked into the mine workings to serve as a support in place of existing pillars when they are reclaimed. This disposal of refuse embodies also the hydraulicking of the breaker refuse directly with the bank refuse. In addition, in many instances, boiler ashes and even refuse breaker rock and “slate” from the breaker are crushed into pea and smaller sizes and hydraulicked into the old or abandoned mine workings. These methods of waste disposal appeal to landowners because they make the valuable space occupied by useless spoil banks available for colliery buildings and for habitation, and assist in solving the problem of how to provide space for needed buildings in mining districts. Several thriving mining villages are at present located on ground previously occupied by spoil banks.

LESSENING STREAM POLLUTION.

Along with the developments mentioned came the realization that river flats, after periodic floods, had been subjected to the deposit of enormous quantities of culm mixed with fine clay, loam, and silt.

^a Davies, J. B., Anth. Coal Operators' Assn., February, 1908; also 1897 Rept. of the Bureau of Mines of the Department of Internal Affairs of Pennsylvania, 1898, p. XXXV.

State and local regulations were directed against such conditions, and a number of civil and criminal suits at law hastened the installation of filling systems whose operation has produced valuable results.

The extent of stream pollution and of land damage as a result of dumping mine refuse along watercourses is often underestimated, but may be realized by a casual survey along rivers with tributaries among the coal fields. Almost every spring the tributaries overflow their banks and enormous quantities^a of culm and silt are washed into the rivers, which deposit the mixture on the lowlands or in the channels down stream. Not only is the transported material a source of destruction to vegetation and improvements along the bottom lands, but the action of the streams involves a great waste of natural resources as proven by the fact, that during each of the years 1910 and 1911 over 90,000 tons of coal was dredged from the North Branch of Susquehanna River several miles below Wilkes-Barre, Pa.

METHODS OF HYDRAULIC MINE FILLING IN THE DIFFERENT FIELDS.

Proper credit has been accorded the middle field in which hydraulic mine filling originated. However, the process, like many others, was studied and the methods were improved by mining men in other sections of the anthracite region. Similarly, in 1893 a party of German engineers visited this country, gave special study to the subject, carried home with them the ideas in practice, and developed and expanded them along the lines well established in the Wyoming Basin, where the method of hydraulic mine filling had been applied in a practical and commercial way. In view of the above facts, it is not altogether surprising to note that the general application of the system in the northern field is considerably more advanced than in the sister fields. This is mainly due, however, to the exceptionally favorable geological conditions.

The beds are much less folded than in the other anthracite fields and large areas of the coal-mine workings are flat. In places folding necessitates chute and pitching workings, especially in the western part of the Wyoming Basin, but their proportion is so small in comparison with the general prevalence of such workings in the middle and southern fields as to be practically negligible. In many localities where filling has been practiced for a number of years, the benefits are being generally realized, and by those who have already benefited by the system it is being rapidly and efficiently extended.

^a Report of the commission appointed to investigate the waste of coal mining with the view to the utilization of the waste, 1893, pp. 133-134.

As previously stated, this process originated in the middle field, but the extent of ground not underlain with coal, the unfavorable geological conditions, and the consequent greater mining cost did not at first necessitate nor make feasible the application of hydraulic mine filling to any considerable extent. In fact, hydraulic mine filling has not been extensively employed in the middle field with a view to realizing greater ultimate coal extraction, but has been adopted locally for surface support, for extinguishing mine fires, and for arresting squeezes. It can not be said that pillar coal is being reclaimed to any appreciable extent by the use of hydraulic filling, but the practice is being rapidly introduced and extended. Experience has taught the miners how to overcome the disadvantages of steep dips and the enormous pressures, from the confined water and filler, on the bulkheads. Also many of the recently planned gangways and chambers are being started with a view to possible hydraulic filling, and crosscuts and airways are being driven in such manner as to favor the future use of such filling.

The southern field, where this system was early used and where it was extensively employed for fighting mine fires, has not developed its installation for economic purposes as rapidly as have the other fields. However, its advantages and its practicable application in the middle field have caused a renewed interest in its application to the steeply inclined workings of the southern field. Especially is its application to the so-called thinner beds, ranging from 4 to 10 feet in thickness, being considered. It must be borne in mind that in this section, as well as in all other sections of the anthracite fields, the beds that were most profitable were developed first and were mined nearly to exhaustion before the thinner and impurer beds were opened and developed. The later development naturally brought improvements in mining methods and also modifications that were adapted to the new conditions. Not so very long ago, when most mining operations were conducted in the Mammoth bed, 30 to 50 feet thick, a bed only 10 feet thick was considered unminable.

MATERIALS USED OR AVAILABLE FOR HYDRAULIC MINE FILLING.

CULM.

The material first used for mine filling was that part of the mined product that passed through the smallest-sized screen used in the preparation of anthracite for market. This fine material is known as culm, a word that is said to be derived from the Welsh term "cwlwm." The material is sometimes called silt.

The entire anthracite field has been explored by operators, individual engineers, and representatives of the Bureau of Mines for

material available for filling mines by the hydraulic method. There are several extensive glacial-till deposits in the northern anthracite field,^a but in the middle and southern fields the hills are mostly composed of hard sandstone, exposed in numerous outcrops, and the covering of soil is generally thin.

The quantity of culm available for hydraulic mine filling depends on various mining conditions which are more or less peculiar to the individual fields. In mining on heavy pitches, as in the southern and middle fields, the quantity of "dirt" and refuse brought down from the coal faces is enormously increased by the crushing and sliding of the larger broken pieces. Breakage in loading mine cars, in transport, and in preparation at the breaker greatly increases the percentage of unmarketable small material. Consequently the quantity of culm is much larger in these fields than in the northern field, where the beds do not dip so steeply and where less fine stuff and impure coal is included in the coal sent to the breaker.

In the whole region the refuse impure coal, and the particles of coal that pass through the smallest-size commercial screen in the breaker are practically of slight value for fuel on account of a lack of suitable furnaces in which to burn them.

In the middle and the southern fields the greater proportion of the run-of-mine product is loaded into the mine cars from the chutes and is taken to rock chutes or directly to the breakers, where the whole product is passed over screens, washed, and separated. In the northern field the methods of mining and preparing coal are somewhat different. The coal is cleaned at the face by the miner and is again cleaned on the traveling tables and the picking tables in the breakers before it passes to the crushers to be broken into the smaller or commercial sizes. The process of breaking down this coal is performed as skillfully as possible, and the smallest possible percentage of culm is produced. The small sizes have some heating value, but unless a market is available for them they must be wasted—either run into the mines or sent to the spoil banks. However, there are few surface spoil banks at the present time, and hydraulic filling is being conducted systematically and applied wherever possible. Thus far culm alone has been the chief material used for hydraulic filling, because of uncertainties as to the source and available supply of other material, such as sand, gravel, loam, and clay, and because of the difficulties of transportation. As a result of the scientific investigations now in progress relating to the utilization of the finer sizes

^a Darton, N. H., Sand available for filling mine workings in the Northern Anthracite Basin of Pennsylvania: Bull. 45, Bureau of Mines, 1913, 33 pp.

for briquetting and firing under boilers by compressed-air blowers the culm may become of commercial value, so that its use for mine filling may ultimately be discontinued.

ASHES.

Although it is considered a part of the efficient operation of an anthracite steam plant to dispose of ashes by mixing them with culm from the breakers and washeries, the idea of hydraulicking this refuse into the mines is of comparatively recent date. With the thousands of tons of coal consumed daily for steam purposes about a large anthracite mine, a considerable quantity of ashes is available for use as filler. These ashes, if properly mixed with the culm and other refuse, make a filler that is easy to transport and becomes compact in the mines. Like culm, ashes will also withstand severe pressure; their compressibility is comparatively small, and their utility as roof support is unquestioned.

Near large cities considerable material for filling can be procured by the collection of ashes and the material excavated in the construction of buildings and in grading streets. All larger cities have systems of collecting ashes and garbage, and by proper arrangement the ashes collected by a city scavenger may be made available for filling mine workings under or near the city. Many industrial plants over mines, particularly over old workings, can make arrangements to hydraulic the ashes from the boilers into the mines by means of bore holes and pipes leading to predetermined points. The ashes from outlying industrial plants and from railroad engine houses might also be made available by being transported in returning empty cars.

CRUSHED BREAKER REFUSE.

An appreciable supply of filling material may be made available by crushing breaker rock, "slate," and bone; also clinkers from spoil-bank fires. An effective method of disposing of the rock separated from the coal dumped into the traveling tables or picking chutes is to convey it to gyratory or swinging hammer crushers, which break it down to chestnut size and smaller and make possible its transportation into the mines through either troughs or pipes. All manner of mine rock,^a except strata between the different coal beds, can be crushed and hydraulicked into the mines.

In most heavy-pitch mining all the material is loaded into mine cars as it flows from the chutes and is dumped into the picking chutes, where the coarse refuse is taken out and sent to the spoil bank. Later the installation of crushing facilities sufficient to crush this

^a In the anthracite region the term "mine rock" includes both top and bottom rock of the coal beds and the partings of shale or "slate."

refuse and make it available for hydraulic mine filling may be practicable. Although the quantity of crushed rock so obtained would be comparatively small, the practicability of its use has not been generally tried out. However, its use no doubt will become more extensive, as it has great supporting value, so that the installation of the additional crushing facilities is undoubtedly a matter of only a short time.

As to refuse from waste-bank fires, this is available only where such fires have burned or are still burning. Experience has taught the futility of attempting to extinguish spoil-bank fires. The only effective way to overcome them is to attack the pile by hydraulic methods, flush the burned material to crushers, and later transport it in similar manner into the mine workings.

SAND, GRAVEL, CLAY, AND LOAM.

The availability of sand,^a gravel, clay, loam, and river silt is limited practically to the northern field. If the various glacial till deposits in the Wyoming and Lackawanna Valleys can be made available the problem of procuring material for hydraulic mine filling will no doubt be considerably simplified. Several attempts to utilize the deposits have been made in various sections of the two valleys and although it can not be said that the undertakings were successful, the abandonment of each of the projects was due more to lack of persistent effort and to crude methods than to the engineering impossibility of the undertaking. In considering the installation of hydraulic-filling equipment, it is necessary to consider the source of water supply as well as the availability of the material to be used.

Clear sand is used extensively as a mine filler in Upper Silesia (Germany), but has been used only to a small extent in the anthracite fields. Medium-size gravel, sand, and loam in moderate proportions make excellent filler. Clay alone does not make a good filler. Sandy loam may be used by itself, but better results are obtained if it is mixed with other material.

The most effective filler is one in which the finer constituents form a cementing bond so that after the removal of the supporting ribs of coal the material will be compact and withstand considerable pressure before sloughing to an angle of more than 45 degrees. When the angle of repose of the supporting material or filler is less than 45 degrees, it is necessary to build confines or dikes—usually called lagging—so as to retain the filler in place. The filler must also serve the purpose of reenforcing pillars and of filling small

^a See Darton, N. H., Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania: Bull. 45, Bureau of Mines, 1912, 33 pp., 8 pls.

crevices in ribs that are beginning to chip or are undergoing "air slack."

In the northern field practically all the available deposits of sand, gravel, clay, and loam are over the worked-out parts of the mines. A considerable supply of filling material may be found in the bars of rivers carrying fine culm, sand, loam, and clay in suspension and depositing those materials at points that make them available for filling if pumping equipment or other means of transportation is installed. The materials may be utilized directly at the place where they lie or at some distance from it by means of bore holes and pumps of various types; the intake of the bore hole should, of course, be considerably above the high-water stage of the river.

In the middle and the southern fields the only available material is found in hillside wash and the soil overlying the rock in the coal basins. Much of the rock is of rather soft and friable texture and might be crushed at a low cost. The material might be hydraulicked to either mine openings and crop holes or to bore holes drilled for the purpose of conducting it to predetermined points in the workings.

It is possible that eventually the price of coal and the quantity of filling material available will become so adjusted that operators will find an advantage in importing such material in coal cars that now return empty to the mines. In such event, suitable filling material will no doubt be found in practically inexhaustible quantities within short hauling distances.

GRANULATED SLAG.

Although granulated slag is used only in Europe, in the vicinity of blast furnaces, it has natural cementing qualities, is very strong, and is seemingly an ideal filling material. It has not been used in this country to any great extent, at least not in such quantity as to show how it compares in cheapness and efficiency with other materials. Along the Lehigh Valley as far east as Bethlehem and in the iron and zinc ore belts of New Jersey large quantities of slag or clinker are available.

CRUSHED ROCK.

Crushed rock and sandstone other than mine refuse has not been used to any appreciable extent, and the practicability of its use is somewhat conjectural. There are large masses of rock within comparatively short distances of many of the mines and some engineers are of the opinion that this rock can be crushed and used for filling at such a cost as to be commercially practicable. The method of transportation is a serious problem on account of the distance the material must be moved. The railroad haul is practically too short

to warrant the expense of loading and unloading under present conditions, and yet the distance that the material must be moved is, as a rule, too great to make sluicing feasible.

The cost of quarrying and crushing suitable rock is estimated at 35 to 75 cents per cubic yard. This charge makes the cost of crushed rock considerably in excess of that of other granulated material, so that it is doubtful whether this material will be much used for filling purposes for some time to come.

Attention is called to the following table^a compiled from tests conducted for Eli T. Connor and William Griffith in connection with their investigations of the mining conditions under the city of Scranton, Pa. The tests were made at the Fritz engineering laboratory of Lehigh University under the direction of Prof. F. P. McKibben and W. H. Conklin, engineer in charge of the laboratory.

^a Griffith, William, and Conner, E. T., Mining conditions under the city of Scranton, Pa.; report and maps: Bull. 25, Bureau of Mines, 1912 p. 55.

Results of tests of compressive strength of various forms of roof support.

No. of test	Construction tested.	Net tons per square foot required to produce compression of—						Compression and load at end of test.		Remarks.
		1 per cent.	3 per cent.	5 per cent.	10 per cent.	20 per cent.	30 per cent.	Compression.	Load.	
1	Rectangular piers of mine rock.		0.8	1.4	2.7	9.5	23	Per cent.	Tons per sq. ft.	Average construction; voids not filled. Well constructed; voids filled with small and shoveled stuff. Average construction.
2	Circular pier of mine rock.		3.5	5.67	11	22	38.5	31	42.5	
3	Timber crib filled with mine rock.		0.6	1.37	5.11	20.3	31.5	46	104.5	
4	Pile of broken sandstone; small pieces.				4	9.3	22.4	45	144	In these tests the material was not confined, but was free to expand laterally.
5	Pile of small-size broken sandstone and sand.			1.6	4	13.5	35	41	75	
6	Pile of broken sandstone; large pieces.		3.6	5	9.1	26.4	37	27	56	
7	Pile of Coal-Measures sandstone similar to No. 6.		2.1	3.5	9	33.4		63	108	In these tests the material was confined and could not expand laterally.
8	Pile of river sand.							35	666	
9	Broken sandstone in cylinder.		3.33	5.55	13.32	46.6	98.6	23	486	
10	Broken sandstone and sand in cylinder.		3.5	5.77	24.42	308.5	25	51	666	This test was made at the Dickson Works of the Allis-Chalmers Co. in Scranton, by William Griffith.
11	Dry coal ashes in cylinder.		1	1.86	5.32	10.8	22	33	608	
12	Coal ashes flushed in with water.		2.44	14.28	35.52	138.7	444			
13	Wet culm flushed in cylinder, partly dried (average of two tests).		8.9							This test was made at the Dickson Works of the Allis-Chalmers Co. in Scranton, by William Griffith.
14	Dry sand in cylinder.		88	3	5.27	33.3	120	32.2	606	
15	Wet sand flushed in and partly dried.		8.4	39.3	67	173.8	555.4	20.75	606	
	Concrete made of cement, sand, and gravel; 4 months old; 1 barrel Portland cement to each cubic yard of concrete (about one part cement to seven parts sand and gravel); piers 3 inches by 2.81 inches by 3.85 inches high.		9	84						

(Gradually crushed to pieces under continuous load of 45 tons)

TRANSPORTATION OF FILLER.

SURFACE TRANSPORTATION.

The breaker or washery by-product that is hydraulicked into the mines is that which passes through the finest screens used in preparing the commercial sizes of anthracite. The openings in these screens are punched and vary from three thirty-seconds to three sixty-fourths of an inch in diameter. To the washery product the waste from the "chippings" elevator or scraper pits is added; by means of a trough the mixture is conveyed to a $\frac{1}{2}$ -inch screen, and what passes through enters the bore hole or the receiving pit. Throughout the Wyoming and Lackawanna Valleys, where the surface slopes are gentle, many of the colliery yards are drained to this same pit, which thus receives the excess storm water.

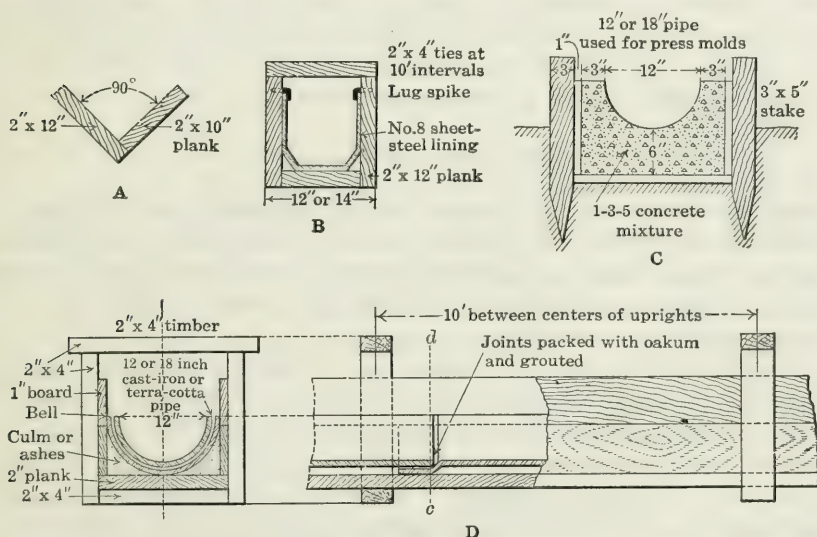


FIGURE 1.—Types of troughs used for surface transportation of mine filler. A, plank trough; B, plank trough with sheet-iron lining; C, concrete trough; D, cross-section on line c-d, and longitudinal section of terra-cotta or cast-iron trough.

TROUGHES.

Where hydraulic mine filling has not yet been introduced the refuse mentioned is collected in a hopper and, by means of gravity lines, pumps, or elevator and scraper lines, is conveyed into troughs or cars to be delivered to the spoil or waste bank. The troughs are constructed of (1) plank (fig. 1, A) or plank with a sheet-iron lining (fig. 1, B and D), (2) terra-cotta or cast iron (fig. 1, D), or concrete (fig. 1, C).

Sheet-iron lined plank troughs.—The sheet-iron lining is generally bent so as to form a semicircle (fig. 1, D) or a half hexagon

(fig. 1, B), and is placed in the plank trough in lapping or flowing joints. Such sheet-iron lining is used only where the inclination of the troughs is less than one-half inch to the foot.

Terra-cotta troughs.—Either round or half-round terra cotta is also used and may be held in place by either boards or concrete. When held in place by boards, a rectangular form is constructed and is partly filled with culm or ashes, so as to form a bedding for the terra cotta (fig. 1, D). Oakum and cement mortar are used to form the joints.

Concrete troughs.—Concrete troughs (fig. 1, C) are constructed in various forms and sizes. The concrete is made of 1 part cement, 3 parts sand, and 5 parts crushed stone. Broken "slate" and rock from the breaker make a satisfactory substitute for the crushed stone, as their resistance to wear is very nearly that of the matrix. The concrete is molded by the use of either a V-shaped wooden trough or a round pipe embedded in it and removed before the final set begins. Whenever large troughs requiring large quantities of concrete are built, large pieces of uncrushed mine rock are embedded in the concrete.

MECHANICAL CONVEYERS.

The mechanical devices in use for the transportation of material on the surface consist of (1) elevators, (2) scraper lines, (3) pumps, and (4) dump cars. In addition, gravity planes may be used where surface features are favorable, and aerial tramways where the surface is rough and broken.

Elevators.—The elevators consist of ordinary sprocket links to which at intervals of about 6 feet are fastened perforated buckets large enough to handle the material as it is deposited in a hopper at the foot of the elevator line. The plane of the elevator is inclined at an angle of about 70 degrees. The length depends entirely upon the height required to furnish sufficient grade for the material to flow through sheet-iron pipes or terra-cotta troughs to the spoil bank, to the bore holes, or to cars.

Scraper lines.—Scraper lines are used to convey the waste culm or refuse over a considerable distance from a common collecting point to the spoil banks or to bore holes. The distance as a rule does not exceed 1,000 feet. Scraper lines are intended mainly for horizontal transportation, whereas elevators are used for vertical transfer. At many mines the distance from the source of the refuse used to the point of entrance to the mine is too great for scraper-line transportation, and pumps are used.

Pumps.—The ordinary piston or centrifugal pump has been found to give the best service in handling the refuse if the material is mixed with proper proportions of water (seldom in less proportion than 10 parts water to 1 part filler). It is good practice to use pipe of the

smallest practicable diameter, thus avoiding the possibility of cross currents or eddies, which are apt to cause frequent blocking of the pipe. Cast-iron pipe, with either bell-and-spigot or flange joints, gives excellent service. After installation the pipe should be turned at stated intervals so as to obtain the maximum wear of the full inside surface.

Dump cars.—Dump cars run on small spurs of narrow-gage track are employed to bring ashes from the boiler plant, which is generally at some distance from the breakers, to the point of common collection, either at the breaker or at the bore hole. Both steam and compressed air have been used to force boiler ashes or breaker refuse through short lines of pipe and have proved effective for the purpose.

INTERMEDIATE TRANSPORTATION.

Intermediate transportation is accomplished through shafts, bore holes, slopes, crop falls, and cave holes.

SHAFTS.

A shaft may be used to contain a pipe line that runs to the lower workings; or if the shaft is not used for hoisting or ventilating purposes, the filler may be run into the shaft, no pipe being employed, and may be allowed to find its way by natural flow into the lower parts of the workings. The use of the shaft without a pipe line is unsystematic; and unless the shaft is shallow, the bed rather steeply inclined, and the workings not very extensive, the practice should be discouraged.

The modern and more systematic method of procedure is to place a pipe line in the shaft (fig. 2, A). This is joined by proper connections (fig. 2, E) to an interior pipe line, through which the material is conveyed to any desired point. The pipe generally is made of wood, terra cotta, steel, wrought iron, or cast iron. The shaft line is securely fastened to the shaft timbering by means of clamps and bolts, so that repairs or necessary changes can readily be made.

Care is taken to have at frequent intervals proper connections to make possible the taking apart of the line without suspending its entire length. The clamps are so constructed that they snugly fit the outside of the pipe and are placed so as not to interfere with taking apart or assembling the various forms of joints. It may not be necessary to place special timbers in any shaft, so that the clamps may be bolted directly to the buntons or wall plates (fig. 2, B, C, and D).

BORE HOLES.

Bore-hole transportation is the method most commonly used, but it involves several important details. The first consideration is the

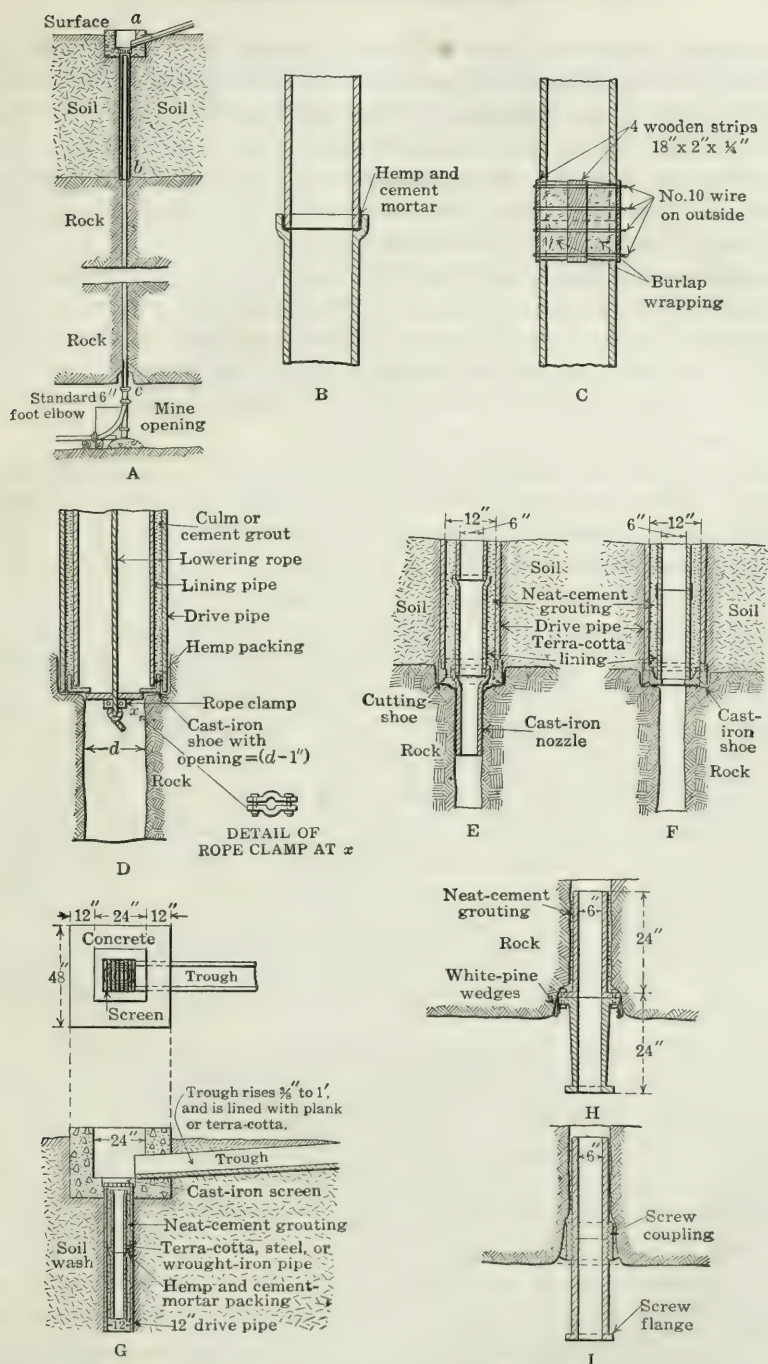


FIGURE 3.—Methods of pipe arrangement in intermediate transportation of filler. A, general cross-sectional view; B, terra-cotta bore-hole lining with bell-and-spigot joint; C, straight cylindrical metal or terra-cotta bore-hole lining; D, method of placing bore-hole lining; E, detail at b , showing arrangement of rock nozzle; F, detail at b , showing alternate arrangement of rock nozzle; G, detail of arrangement of parts at a ; H, detail of arrangement of parts at c ; I, detail of alternate arrangement of parts at c .

pieces and removed if it wears out. It may be constructed with special lock flanges or with ordinary bell-and-spigot ends. On account of the large diameter of hole required for standard flange joints, such joints are impracticable. Ordinary bell-and-spigot joints are packed with oakum and cement mortar as the pipe is lowered into the hole. The terra-cotta lining is either of the plain cylindrical type or of the bell-and-spigot type.

In using the plain cylindrical terra-cotta pipe the lengths are joined by means of a triple thickness of burlap wrapping extending about 9 inches on either side of a joint. The wrapping is stiffened with 2 by 4 by 18 inch wooden strips firmly held in place by bands of No. 10 galvanized wire. The three types of lining described above require rock nozzles (fig. 3, E and F).

The method of inserting the pipe in the bore hole is briefly as follows: From a tripod, or the rocker arm of the drilling machine, a single-sheave pulley is suspended. Through the pulley is passed a hemp rope of sufficient strength to support the full length of lining pipe. To the end of the rope a clamp is attached above a knot in the rope. The clamp supports a circular plate of a diameter 1 inch less than that of the hole in the rock. This plate supports the cast-iron rock nozzle or shoe, which in turn supports the lining pipe. About 3 feet above the ground another clamp is placed on the rope. The rope is paid out on the ground the full length. Two lengths of terra-cotta lining pipe are passed over the rope and the pulley is hung from the tripod or the walking beam of the drilling machine, care having been taken to pass the pulley through the lengths of pipe so that its position is between the bottom clamp and the loose end of the rope. The loose end of the rope is then passed around the drum of the drilling engine three or four turns and the slack taken up. This brings the lining pipe in a vertical position over the hole.

The joints are then packed with oakum and cement mortar, and the pipe is lowered into the hole until its upper end is nearly flush with the top of the drive pipe. The rope is clamped and held in position by the lower attachment, the block is taken down, the rope is paid out on the ground as previously, and two more lengths of pipe are strung on. The block is again attached to its hangings, the slack of the rope is taken up by means of three or four turns on the engine drum, the whole string is lifted so that the clamp can be removed and the additional pipe connected to the two lengths already placed, and the joints are packed, the pipe lowered into the hole, and the rope clamped as before. This process is repeated until the entire lining has been inserted. The space between the outside of the lining pipe and the inside of the drive pipe is then filled with cement grouting.

When ordinary screw-sleeve gas-pipe lining is used, it is lowered into the rock for several feet in order to insure perfect discharge and the protection of the rock joint and the drive pipe. Such lining pipe is suspended by means of clamps over the receiving basin, usually of concrete, and is protected by means of a screen similar to that shown in figure 3, G. At the bottom or foot of the bore hole, either a special cast connecting piece, as shown in figure 2, E, or figure 3, H, or a short piece of wrought-iron pipe fitted with a screw flange is inserted up the hole for 2 or 3 feet (fig. 3, I). The space between the outside of the connecting piece and the wall of the bore hole, after having been packed with hemp, wedges, or burlap, is filled with a grouting mixture of proper consistency.

BLOCKING OF BORE HOLES.

A serious source of trouble, and in many instances of prolonged delays, has been carelessness on the part of the person in charge of the intermediate transportation, usually manifested either by poorly regulated water supply or by large pieces of filler being allowed to pass the top screen. If through such carelessness the hole is blocked, reopening may entail considerable expense. To lessen the delay it has been found expedient to have ready for insertion at any time a water pipe an inch or an inch and a half in diameter with a steel point and a series of holes extending 2 or 3 feet above the point. When the bore hole becomes blocked, the foot elbow is removed, the pointed pipe is inserted, and water under high pressure is turned into it. The water thoroughly saturates the filler and causes it to pass off at the bottom.

Another method of reopening is to attach short lengths of 1-inch to 2-inch pipe, connect these to a mine column line, and force water up into the hole, thus washing out the material. In case it is impractical to arrange for reopening by water jet from below, the use of a long pointed iron rod, about 2 to 3 inches in diameter, raised and dropped from the surface by means of a windlass, has sometimes been found effective, but in general this is bad practice and should be discouraged. Where the influx of filler and water is irregular it may be expedient to turn a small supply of water, say a 1½-inch pipe running full, from an independent source into the receiving hopper at the surface.

RELINING BORE HOLES.

It frequently becomes necessary to change the lining of the bore hole because of unequal erosion; the drive pipe is sometimes destroyed in sections, and surface water and sand or gravel flow into the hole and cause serious expense or the blocking of the hole. In many such cases it has been necessary to drive a pipe over the origi-

nal drive pipe and remove the damaged drive pipe by means of a chopping bit. This procedure is, of course, very slow and expensive; and if the mine is being damaged by water or sand flowing in through the abandoned bore hole, it is cheaper to drill a new hole and fill the old one with concrete. If, however, the lining only is affected, which may be readily discovered by observing the nature of the filler deposited, the operation of reopening is simple if the lining consists of earthen pipe or nonmalleable iron pipe. An ordinary drilling rig and a chopping bit are employed, and all the broken material, such as lining and cement grouting, is lifted from the hole with a sand pump. A new lining, with its accessories, is then placed in the same manner as was the original lining.

If a loose, uncemented metal lining pipe is used, it may readily be withdrawn from the hole by means of tripod, block and tackle, and windlass. It is, however, highly important that the practicability of having duplicate holes be kept in mind. A second hole should be provided wherever possible, and in order to insure the proper operation of both holes the filling material should be run through each on alternate days.

With few exceptions it is more economical to drill a new bore hole when the lining wears out. This is particularly true if the metal lining extends through the rock and into the mine, as was the old custom, or if the lining is grouted.

SLOPES.

If the hydraulic filling is to enter the mine by means of a slope, a pipe is placed with appropriate facilities for anchorage. Anchorage may be accomplished by the use of mud sills (*a*, fig. 4) to which the pipes are fastened by means of clamps and rag spikes, or by rag-spiking the clamps directly to props set for this purpose (*b*, fig. 4), also by suspending the pipe line by a chain with one lap around the pipe and fastened to the roof or the props. On account of the great expense entailed in placing the pipe, it is economical to use for this purpose wood-lined pipe in sections having cast-iron flanges held together with bolts, eight or more in number, depending on the pressure in the line.

CAVE HOLES.

In places the surface subsides very slowly over old abandoned mine workings, especially where the beds are thick and the pillars left have been too small; eventually over such mine workings cave holes appear which are often a nuisance as well as a possible cause of injury to unsuspecting trespassers. In order to close such unsightly and dangerous holes, filling material is delivered to them and allowed

to enter the workings and fill as many of the openings as the inclination of the workings and the passageways available will permit. When the cave holes are filled to the former level of the ground, the danger to either life or property is of course removed.

UNDERGROUND TRANSPORTATION.

The method of conducting filler from the receiving point to the openings to be filled requires careful study and intimate knowledge

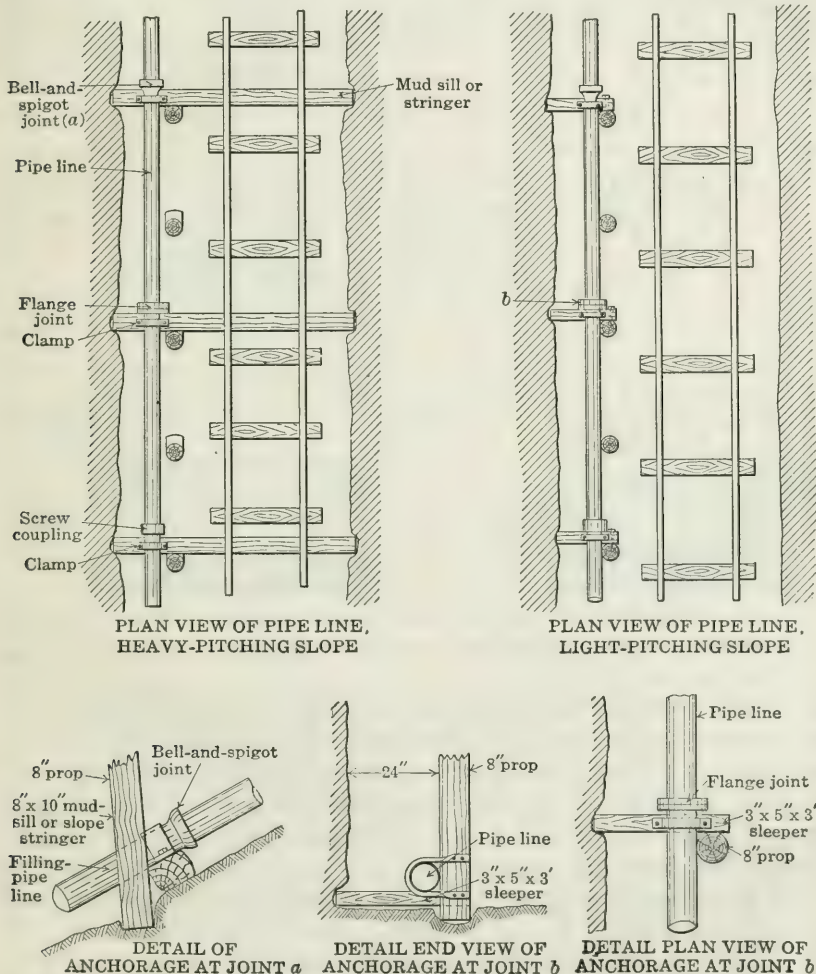


FIGURE 4.—Methods of pipe arrangement in intermediate transportation (slopes).

of the physical features of the mine. It is obvious that a flat mine offers considerably greater difficulties than one working moderately inclined beds and much less than one working heavy-pitching beds. The various methods that may be used, from the cheapest, although

probably not the most economical, to the most systematic and therefore the most expensive method, are here presented.

UNCONFINED FLOW.

When the filling material is discharged into the mine freely, as from a shaft or bore hole, there must be sufficient inclination below the point of discharge to cause a current that will hold the material in suspension. Consequently, in horizontal or flat beds the moving of filler by unconfined flow is impracticable. In beds with an inclination greater than 10° transportation by unconfined flow is practicable if the material is not to be delivered at too great a distance from the point of influx. By some care in planning, or under

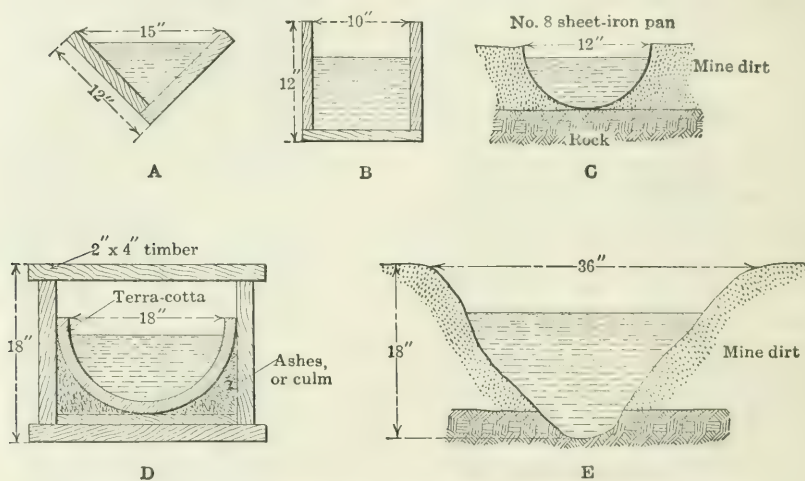


FIGURE 5.—Types of troughs and channel for underground transportation.

the supervision of a careful miner, a dirt ditch or channel (fig. 5, E) may be washed out and the filler conducted satisfactorily into the openings to be filled. Great pains, however, should be taken to maintain the channel in such condition that it will not become blocked or dammed, thus avoiding a source of considerable expense and damage. Such damming renders filling by unconfined flow dangerous when practiced in sections of higher elevation than those in which men are employed. In one instance a dam was formed by a partial obstruction in the channel. The slow seepage of the bearing water permitted a large quantity of material to accumulate, and eventually the accumulation started and rushed down the lower workings, into a section that was to be filled, with such force as to destroy the bulkheads and fill up traveling ways and air courses.

TROUGHES.

Where the inclination of the coal bed is between 5° and 10° , troughs lined with sheet iron (fig. 5, C), terra-cotta (fig. 5, D), or even unlined (fig. 5, A and B), are used to convey the filler from the bore hole or shaft to the opening prepared for it. A considerable saving in the construction of troughs can be effected by the use of sheet-iron pans (fig. 5, C). The sheet iron is bent in such a manner as to form a semicircular or semihexagonal section, and by placing the sheet-iron lengths in lapping joints the filler can be conducted directly to the desired point, the cost of constructing and removing wooden troughs being thus saved.

PIPE LINES.

In horizontal or ascending workings it is necessary to employ pipes of wood, steel, wrought iron, cast iron, terra-cotta, porcelain-lined, or glass.

WOOD-STAVE PIPES.

Wood-stave pipes are probably the type most extensively used. The staves, of the regulation tongue-and-groove type (fig. 6, A), are made of hard wood, such as oak, ash, or maple, and form a pipe that is economical and highly serviceable. It is spirally wound with galvanized wire or steel bands and is given a protective coating of tar, sprinkled with "granolithic" sand, slag, or sawdust. The wire winding proves most serviceable, as the area subject to the attack of acid water is minimized, yet the wire forms a strong protection. Connection of the lengths of pipe is made by the usual male and female ends (fig. 6, B). This form of connection does not permit easy and relatively cheap cleaning of a line in case of blockage, nor does it permit the introduction of elbows, bends, tees, or valves. To overcome this objection cast-iron or wrought-iron flange connections are inserted into the line (fig. 6, C). These necessitate the use of short pieces of pipe with two male ends (fig. 6, D), as the cast-iron or wrought-iron flange connections are usually constructed for male connections. The flange connections are easily disconnected, so that in case of blockage the lengths of pipe can be rolled out of line and cleaned. One of the greatest advantages of the flange-connecting pieces is that they permit easy and inexpensive turning, so that the maximum service is obtained from the pipe.

STEEL AND WROUGHT-IRON PIPES.

Where the working pressure or water hammer on a pipe line is liable to exceed 100 pounds per square inch, steel, cast-iron, or wrought-iron pipes are used. Connections are effected by either screw or flange joints (fig. 7, A and C) or by plain sleeve couplings (fig. 7, B). The sleeve of the plain sleeve coupling is packed with oakum,

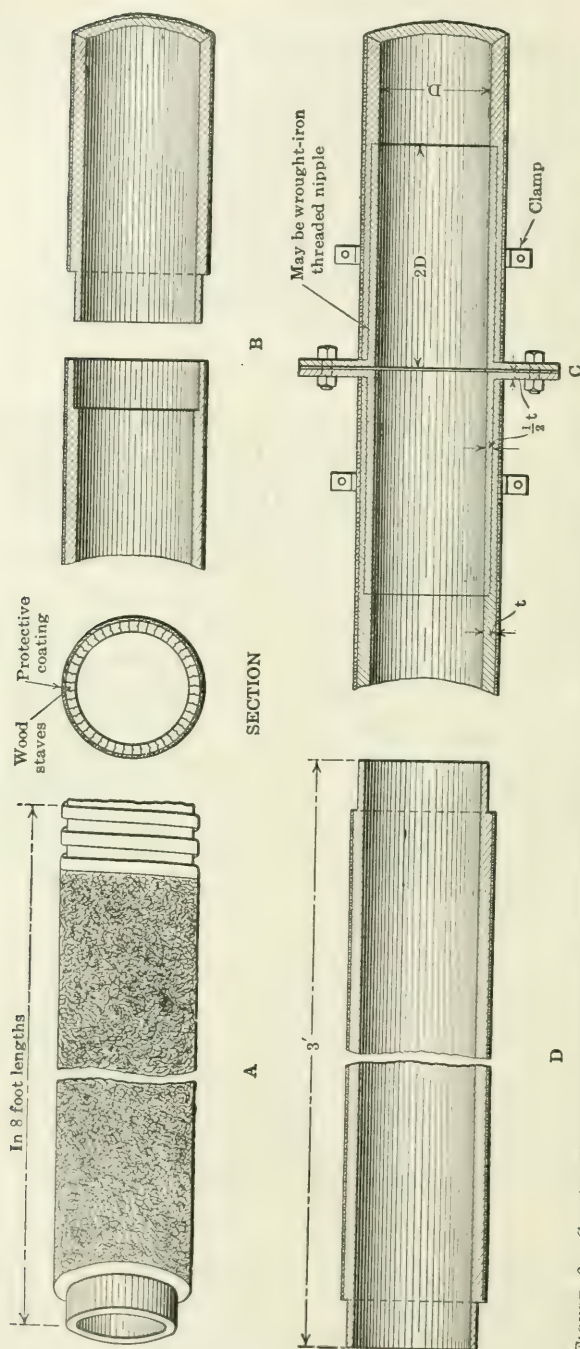


FIGURE 6.—Construction and connections of wood-stave pipe. A, regulation 8-foot length of wood-stave pipe, showing metal-band wrapping with tar and sawdust coating; B, male and female ends; C, standard cast-iron flange coupling; D, short-length pipe with male ends for use with wrought-iron flange coupling.

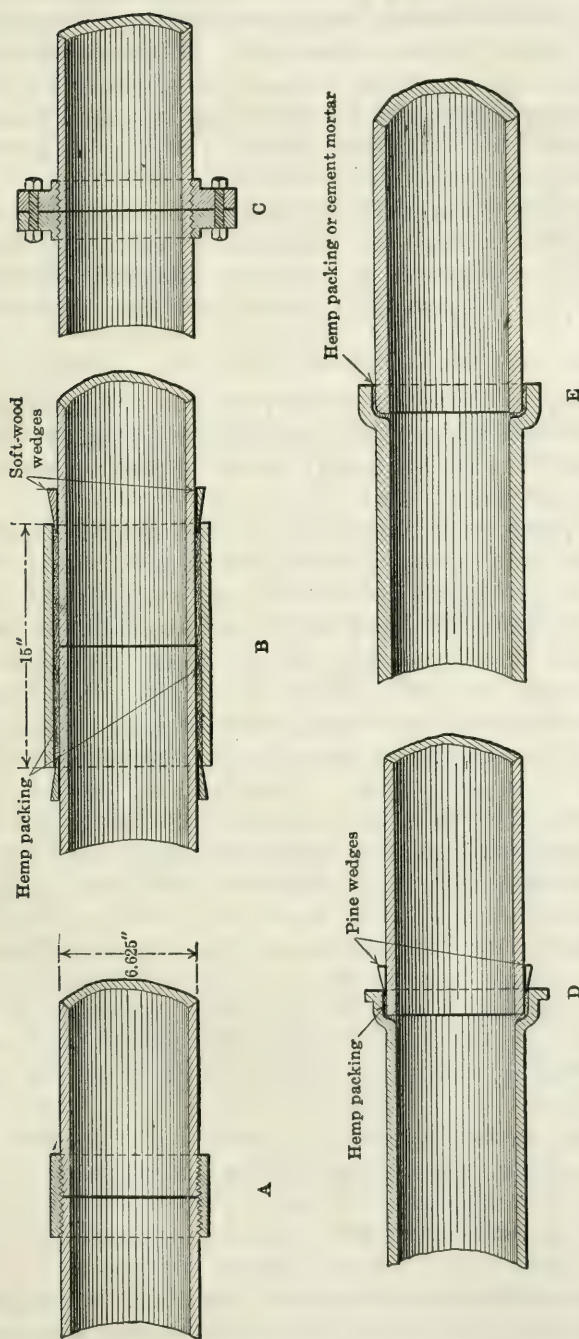


FIGURE 7.—Connections of metal and terra-cotta pipes. A, screw coupling; B, plain sleeve; C, standard flange coupling, 6 bolts; D, east-iron bell-and-spigot connection; E, terra-cotta pipe connection.

burlap, or strands of old or discarded hemp rope, and white-pine, hemlock, or other soft-wood wedges are driven sufficiently close to each other to make the joint water tight. When water and filler are first turned into the pipe there is considerable leakage, but the oakum or other packing becomes filled with silt and in a short time the joint becomes water tight. This type of pipe is popular on account of its low price and wide range of application.

The flange-joint pipe offers advantages somewhat similar to those of the plain pipe except that flange joints are not as easily kept tight and are not adaptable to irregular alignment. Obviously, the cost of such pipe is considerably greater than that of the plain pipe.

CAST-IRON PIPES.

Where lines are installed with the probability of remaining in one place for a considerable period, especially those along traveling ways or air courses that are constantly under inspection, cast-iron pipe (fig. 7, D) is extensively used.

This pipe possesses the advantage of wearing with a continuously smooth surface and offering little resistance to the flow of the filler. The types of connections most extensively used are the flange and the bell-and-spigot. The bell-and-spigot connection is used more frequently for filler pipe, whereas the flange connection is used almost exclusively for pump-column lines. The bell-and-spigot connection is made tight by the use of oakum packing or short pieces of old hemp rope, and is firmly secured with white-pine or other soft-wood wedges.

The abrasion of the filler keeps the inside of the pipe smooth at all times, so that the frictional resistance, it is claimed, is considerably less than in wooden pipe. The feature of cast-iron pipe that gives it wide adaptability is its being made in 12-foot lengths, which, although necessitating the expense of frequent connections, afford physical advantages, such as the possibility of irregular alignment, that are not obtainable with other metal pipes, which are made in longer lengths, usually about 20-foot. The life of cast-iron pipe is about twice that of wooden pipe and about six times that of steel or wrought-iron pipe.

Wood-lined cast-iron pipe has been used in several mines, particularly on slopes, but its use is not common. The pipe has a cast-iron flanged shell with a wood-stave lining. When water is introduced, the wood lining tends to expand or swell and thus make a firm contact between it and the inner wall of the cast-iron shell. The pipe possesses the wearing and acid-resisting qualities of wood pipe and of ordinary cast-iron pipe, but by reason of the expensive outer shell and the rather short life of the wood lining, unless it is carefully and

frequently inspected, many blockages occur on account of the lining wearing out, so that the general application of this form of pipe can not be said to be probable.

TERRA-COTTA PIPES.

In places where there is slight danger of damage from falls of roof or other external sources of injury the use of terra-cotta pipe (fig. 7, E) may be safely and economically adopted, especially if there is no back pressure on the line. The expense of frequent joints should, however, be avoided if practicable. The pipes are manufactured in 3-foot to 4-foot lengths. Ordinarily, the joints are packed with hemp or oakum with a thin layer of cement mortar as surface packing. The cement mortar is held in place until firmly set by means of a wrought-iron clamp bolted flush with the edge of the bell flange. Terra-cotta pipe, however, offers considerable frictional resistance on account of the rapid abrasion caused by the filler which soon wears off the smooth glaze. Especial care must be exercised and close supervision enforced so that the pipe will be turned in sections at proper intervals to obtain the maximum wear. The pipe can be advantageously used on all descending lines in flat workings where the filler is to be conveyed directly to the bulkheads.

PORCELAIN-LINED PIPES.

Porcelain-lined pipe has been extensively used with excellent results in European plants, although in some mines it has not been so successful and has been replaced by plain metal pipe. Owing to its high price in this country and to the difficulties of manufacture the cost of this type of pipe is so great as to make its use impracticable for hydraulic mine filling in the United States under present conditions.

GLASS PIPES.

In order to avoid the heavy expense of renewing elbows and other bends in filler lines, a remedy was sought in the use of glass pipe, particularly for bends of 45° to 90°. The experiment, however, has not proven an entire success, and the use of glass pipe will probably be desirable only under special conditions.

COMPARATIVE EFFICIENCY OF VARIOUS KINDS OF PIPES.

It must be borne in mind that wherever pipes or bore holes are used for the transportation of filler the filling must be conducted with judgment. Under no circumstances should filler be turned into a bore hole or pipe line until considerable water has been run through to remove any pockets of sediment that may have formed. Water should also be run through after the flow of filler has been turned

off at the completion of the day's work, so that the material will be completely flushed out.

In stating the efficiency of various kinds of pipes employed for hydraulic mine filling, it must be borne in mind that accurate experimental data are not available. However, the observations made below are believed to be warranted. Proper regard must, of course, be had for the geological conditions under which any of the methods is operating. For example, where the grades are undulating it is absolutely necessary to have a stout metal pipe unless the back pressure is comparatively light. Roughly, such pipe should be used when there is a difference of 100 feet between the highest and lowest points in the line. At no point throughout the system should the velocity be less than 6 to 8 feet per second. This will insure against deposition of the filler in the line.

A brief discussion of the merits of the different kinds of pipes mentioned above follows.

WOOD PIPE.

ADVANTAGES.

Wood pipe possesses a number of distinctive advantages. (1) It is immune from chemical attack; (2) it has a tough wearing surface; (3) it is easily turned; (4) it is easily cleaned; (5) its cost of installation is low; (6) it can be used under difficult physical conditions.

Immunity from chemical attack.—The chemical attack on pipe used in hydraulic filling is of great importance, especially where ashes or other acidulous filler is employed. This attack is exerted not only on the filler pipe itself, but on pumps and drainage columns as well.

Tough wearing surface.—Wood pipe has a tough wearing surface, and although somewhat less durable under steady use than metal pipe of equal thickness, it is not impaired by rusting, as is metal pipe when the line is unused for some time. Wood pipe will wear much longer if it is frequently turned slightly, say one-eighth to one-fourth turn at a time.

Ease of turning.—Being in short lengths, wood pipe can be turned with less expense than metal pipe, especially if cast-iron flange connections are placed in the line at rather frequent intervals, say every 30 feet.

Ease of cleaning.—Because of the flange connections and the short lengths of the pipe, blockages are cleaned and pipes reopened at practically minimum expense, especially where the material has to be withdrawn by scrapers or punching rods.

Low cost of installation.—The lightness of wood pipe permits easy and inexpensive handling and the cost of placing or installing is therefore reduced to a minimum.

Adaptability to difficult physical conditions.—Wood pipe can be installed with comparative ease under difficult conditions, such, for instance, as are found in old and caved workings. The lengths can be connected so as to allow considerable deflection in vertical and horizontal alignment.

DISADVANTAGES.

The disadvantages attendant on the use of wood pipe are: (1) It dries out and collapses when not regularly in use; (2) it wears unevenly; (3) it easily springs out of line; and (4) its life is comparatively short.

STEEL AND WROUGHT-IRON PIPE.

All exposed surfaces of steel or wrought-iron pipes are subject to corrosion. The effect is serious and should receive careful attention when a filling system is being planned. The wearing surface of metal pipes, although smooth, is subject to strong abrasion from the rapid cross currents and eddies in the flow. The point at which the greatest wear will occur can not be definitely fixed as the wear varies greatly. No particular precaution can be followed other than turning at frequent intervals. Where screw thimbles or screw joints are used, turning becomes rather complicated and requires a number of men, whereas if the slip-sleeve or flange connections are used the expense is considerably reduced.

Screw joints do not permit pronounced variation in alignment unless, before the pipe is placed, it is bent to conform with the alignment so that the use of flange connections becomes necessary. If a line is "sprung" around curves the outer wearing surfaces are subject to considerable strain in addition to the centrifugal force in the current and leaks and failures of the pipe result. Steel or wrought-iron pipe is more difficult and expensive to clean than is wood pipe on account of the lengths being longer and also less easy to remove unless flange connections are used.

One of the greatest disadvantages of this type of pipe is its tendency to corrode. Each morning considerable care must be observed when the mixture of water and filler is turned into the line as otherwise blockage from friction caused by the corrosion overnight may be the first thing to occur in a day's operation.

CAST-IRON PIPE.

Although there is a serious objection to the weight of cast-iron pipe of standard length (12 feet) this pipe has become rather popular for use in hydraulic mine filling. The bell-and-spigot connection allows great flexibility in vertical and horizontal alignment and because the

pipe keeps a smooth surface during use the proportion of water and the velocity of the current can be reduced to a minimum. On account of the short lengths in which cast-iron pipe is made it can be installed in caved and tortuous openings. The wearing surface must be thoroughly washed twice a day, before and after filler has been introduced, in order to guard against frequent and expensive blockages. Cast-iron pipe is easily turned if either the bell-and-spigot or the flange type of connections is used.

It should be borne in mind that all pipes when installed will sooner or later have to be removed for cleaning and should be so placed that this can be accomplished at the least expense in labor and material. When bell-and-spigot connections are used, it is advisable to insert at intervals of 48 to 80 feet flange connections so that sections of pipe can be rolled out of line and cleaned or new sections put in.

Cast-iron pipe is subject to the corrosive effect of acid water, and although it deteriorates less rapidly than pipe made of wrought iron or steel, nevertheless such water has a very destructive effect and shortens the life of the pipe decidedly. It is claimed that under a pressure of 100 pounds to the square inch cast-iron pipe will wear three times as long as wrought-iron and about five times as long as steel pipe.

WOOD-LINED PIPE.

Wood-lined pipe is used only in special cases, as in shafts or slopes. In some mines, especially where the mine water is highly acid, it has been expedient to use the filling line as a water column during the night, the main trunk line being suitably connected to the mine pump. However, on account of the great expense and the rapid wear of the wood lining, this practice now is practically discontinued in favor of the more effective plan of having separate lines, usually of cast iron, with bell-and-spigot connections, for the filling pipe and flanged wood-lined pipe for the water column.

TERRA-COTTA PIPE.

The use of terra-cotta pipe for underground transportation is rather restricted. The cost of this pipe is comparatively low, but it lasts only a comparatively short time. On account of the texture of the body of the pipe, as soon as the inner glazing is cut through erosion is rapid, and of course there is considerable resistance to the flow of filling material.

GLASS PIPE.

Glass pipe has been tried only as an experiment in the hope of obtaining a good wearing material of low frictional resistance that might be used particularly where there are changes in alignment, as

in bends or elbows. Although glass pipe offers several advantages, its use will hardly become popular, especially for a straight line. Its use was expected to eliminate the serious trouble experienced in metal pipe lines at a point some distance beyond a curve or bend. Pipe frequently wears beyond the bend or at the joint next beyond the bend. Consequently, glass elbows have been tried that are of special thickness just beyond the bend. These elbows wear longer, but the cost of glass pipe practically prohibits its general use, even for elbows.

PORCELAIN-LINED PIPE.

Porcelain-lined metal pipe has been used extensively in Europe, but on account of its great cost in this country its application has been impracticable. The metal shell is usually of wrought iron or steel, and the lengths are provided with flange connections. The porcelain lining is about one-half inch thick and is divided into sections about 10 or 15 inches long. The space between the metal shell and the porcelain lining is filled with a cement grouting. Eight bolts are generally used to bind together the flange joints.

The wearing qualities of porcelain-lined pipe are considerably greater than those of plain metal pipe, and the frictional resistance is considerably lower. However, when coarse material is transported the necessarily high velocity of the current in the pipe line causes the larger material to impinge on the walls of the pipe; the continual impact tends to crack and break the porcelain lining and thereby destroy its efficiency.

USE AND CHARACTER OF BULKHEADS.

The construction of the bulkheads to be placed to retain the filler in mine workings should be given careful consideration. The conditions in the workings to be filled should be carefully analyzed with a view to determining the most economical and at the same time the most efficient type of bulkhead.

TERMS USED IN ANTHRACITE FIELDS.

In selecting a suitable term for the mine construction that holds the filler in confinement due regard was given other terms used in the Pennsylvania anthracite fields. The term "battery," probably the most widely employed, offered the objection of being a commercial term having electrical and mechanical significance. The term is also applied to wooden barriers for coal chutes in pitching beds. Its general use therefore might cause confusion.

The term "dam" is generally used to signify a water-tight permanent construction to confine large quantities of water within certain limits, the confining material being usually earth, stone, concrete, or

square timber. General usage in connection with hydraulic mine filling has developed this misnomer, and the term is frequently modified, as "slush," "flush," or "silt" dam.

The term "stopping" was rejected because of its general use in connection with the control of ventilation.

The term "bulkhead" is believed to be distinctive, and as used in this bulletin signifies a device having the usefulness of the type of retaining wall, constructed of various kinds of material, now being employed to confine filling material in the reclamation of beach-front lands.

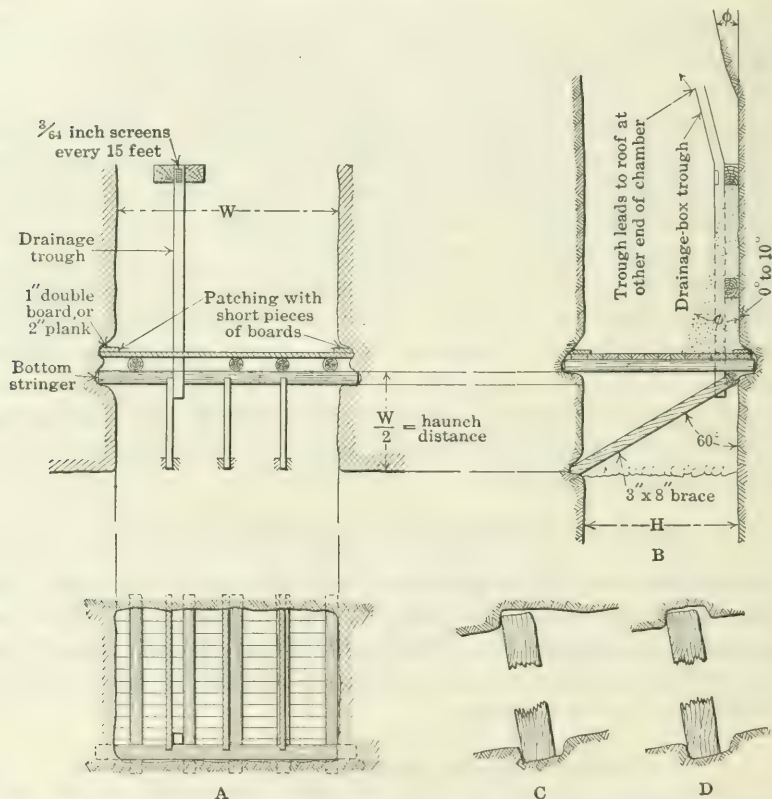


FIGURE 8.—Bulkhead and hitches for flat workings. A, plan view and front elevation; B, side elevation; C, prop held by a sliding and a trough hitch; D, prop held by trough hitches.

GENERAL RULES OF CONSTRUCTION.

The method of construction and the details of the various types of bulkheads used in common practice are greatly influenced by the geologic conditions, particularly by the inclination of the coal bed. The height of the bed, the width of the opening to be closed, and the character of the coal ribs into which hitches are cut for anchorage are also important factors.

The construction must permit proper drainage, possible future use in ventilation, and the reopening of the filled section in such manner as to make second mining possible at minimum expense.

The type of bulkhead used throughout the anthracite field is practically the same and is generally that first adopted, with the improvement of a few minor details. However, several details can be still further improved.

Mine workings (chambers) should be so opened as to entail the least possible expense in bulkhead construction. Instead of full-width chambers, the openings should be as narrow as haulage and ventilation will permit.

In general, bulkhead construction is considered a part of timbering. The haunch distance (fig. 8, A; fig. 9, and fig. 10, A)—that is, the distance along the rib from the entrance opening to the bulkhead hitches—should be equal to one-half the width of the opening for flat and chute workings and two-thirds the width of the opening for pitch workings.

As to the props used, their diameter in inches should be equal to their length in feet for flat workings, or to a multiple of corresponding lengths for chute and pitch workings, plus the depth of the top and bottom hitches in feet. The empirical formulas for the diameter of props are as follows:

$$\begin{array}{ll} \text{Flat workings} & \text{..... } D = \frac{L}{1} \\ \text{Chute workings} & \text{..... } D = \frac{3L}{2} \\ \text{Pitch workings} & \text{..... } D = \frac{7L}{4} \end{array}$$

L=length of props, in feet.
D=diameter of props, in inches.

Formulas for the spacing of props are as follows:

$$\begin{array}{ll} \text{Flat workings} & \text{..... } S = \frac{W}{H} \\ \text{Chute workings} & \text{..... } S = \frac{2W}{3H} \\ \text{Pitch workings} & \text{..... } S = \frac{4W}{7H} \end{array}$$

W=width of opening, in feet.
H=height of opening, in feet.
S=spacing of props, center to center, in feet.

Obviously the number of props required in a bulkhead is:

$$N = \frac{W}{S} + 1,$$

in which W represents the width of the opening in feet and S represents the spacing distance in feet.

The materials of construction to be employed depend upon the form and type of bulkhead to be erected. In general, it may be said

that props and plank, gob, dirt, blasted rock, concrete, and stone are usually adopted. In conjunction with these materials, limestone and calcareous shales have been used to neutralize sulphuric acid in the water. Packing, necessary to avoid excessive leakage and to form a filter curtain or "screener," may consist of burlap or brattice cloth, hay, shavings, manure, ashes, straw, forest leaves, etc.

Props and planks or boards are used for practically all flat workings. Timber, gob, stone, and concrete bulkheads are generally constructed where the dip of the coal bed is steep and the workings are comparatively new. The bulkheads can then be utilized to assist ventilation before actual filling is undertaken. Packing is used only on inclined workings and the quantity is almost proportional to the degree of inclination. Its purpose is to filter out of the seepage water any filler held in suspension. Care must be exercised not to make bulkheads too water-tight, as allowance must be made for partial relief of hydraulic head.

DETAILS OF BULKHEAD CONSTRUCTION.

Bulkhead construction, although chiefly in charge of the boss timberman, generally receives the careful attention of the colliery officials in charge, who possess thorough knowledge of the geological as well as the physical features of the workings to be filled.

After the section of the mine to be filled has been determined, the selection of bulkhead locations is considered. The materials suitable and the type of bulkhead to be constructed are carefully investigated, especial attention being given to the cost of the materials. The cutting of hitches, vertical and horizontal, is left to the foreman in charge, who is thoroughly familiar with the character of the coal and the rock at the determined locations. In general practice the depth of the hitches is equal to the diameter of the props. The vertical hitches are cut into the coal ribs parallel to the plane of the props; the horizontal hitches are cut into the bottom (floor) and the roof along the line of intersection of the plane of the props. This plane deflects from the normal ^a up the pitch 2 to 10 degrees, depending on the dip of the bed. If the dip is less than 80 degrees, the deflection, as a rule, is equal to about one-seventh of the dip.

TIMBER BULKHEADS.

Timber can be used for all kinds of bulkhead construction, but is especially suited for use in flat and chute workings.

^a By normal plane is meant a plane at right angles to the plane of inclination, or dip, of the coal bed.

BULKHEADS FOR FLAT WORKINGS.

Roof or bottom (floor) hitches in hard standstone are cut one-half the depth of those in shale or "slate." The bottom hitch is generally of the trough type (fig. 8, D), whereas the top is more frequently of the sliding type (fig. 8, C), especially where the roof is hard. The spacing of props usually follows the formula previously cited for flat workings ($S = \frac{W}{H}$). For example, for a room 8 feet high by 24 feet wide the props should be 8 inches in diameter ($D=L$) and spaced 3 feet apart center to center. By formula $N = \frac{W}{S} + 1$

a single row of props would be sufficient for a chamber of such size. If the roof and the floor are of shale or "slate," the hitches would be cut as trenches 12 inches wide and 8 inches deep. Where the roof and the floor are sandstone the hitches would be cut separately 10 or 12 inches square, but only one-half as deep as in the shale or "slate." This difference in cutting is made because shale or "slate" exposed to air and moisture swells or "heaves," causing in many places serious cracks in the bottom or roof and initiating so-called "water squeezes," whereas in sandstone such action seldom occurs.

The props are securely wedged at the top and manure or dirt is firmly packed around the bottom after the bottom plank has been attached, so as to avoid leakage. One and one-half inch plank or double 1-inch boards are then nailed to the inside face of the props for the entire height. The bottom, sides, and top are carefully joined or "patched" with short pieces of board nailed to the main boarding and the solid coal or pillar. If the dip of the bed is between 5° and 15° , a straw, hay, burlap, or brattice-cloth packing is used; or, in order to avoid heavy hydraulic head, a drainage trough to draw off excess water may be constructed as illustrated in figure 8, A and B.

BULKHEADS FOR CHUTE WORKINGS.

Chute workings, as previously defined, are understood to indicate workings in beds inclined more than 10° and less than 25° and where the lining of chutes with sheet iron is necessary to cause the coal to slide to the foot of the chamber on the loading platform. The heavier hydraulic pressure on bulkheads in such workings naturally demands a more massive and substantial construction than is required for flat workings. The character of the overlying and the underlying rock influences the construction to a certain degree as regards obviating water squeezes.

Where the inclination of the bed is 18° or more, manure, straw, or hay is placed between the two courses of boards as a "screener," and in many places a wall of dry gob is constructed to act as a partial filter.

BULKHEADS FOR PITCH WORKINGS.

Pitch workings, as previously defined, include workings in which the inclination of the bed exceeds 25° and in which the coal will run in chutes or troughs not lined with sheet iron. As the pressure on bulkheads in such workings is greater than on the bulkheads previously mentioned, it is obvious that the construction and the materials must be heavier and more substantial.

Assume a chamber 10 feet high by 24 feet wide. The diameter of the props, according to the formula $D = \frac{7L}{4}$, should be $17\frac{1}{2}$ inches or, say, 18 inches; the hitches should be of the trough type, from 10 to 18 inches deep, and wide enough to allow manure and dirt packing around the props and bottom plank. The spacing, according to the formula $S = \frac{4W}{7H}$, should be 1.4 feet, or, say, 17 inches, from center to center. As this spacing is less than the maximum diameter of the props, and as, by the formula $N = \frac{W}{S} + 1$, the number of props required is 17, two rows will be necessary. The extra props should be so distributed as to make the total supporting value equal to that of the entire number of props required, and they should be so placed as to give a clearance of at least 6 to 8 inches; therefore, substituting in the formula $N = \frac{W}{S} + 1$,

$$\frac{24}{a1.5 + b0.5} + 1 = 13$$

The number of props to be placed in the first row is therefore 13; the remaining 4 (17-13) props are for reenforcement. The reenforcing props might be applied as three horizontal braces, as indicated in figure 9.

If the bulkheads are intended to withstand great pressure in beds of steep dip, the form of an inverted **V** is most preferred (fig. 10).

The bottom and top hitches are cut continuous, as are the rib hitches. When timber is used, the sticks are laid parallel to the dip of the bed in the form of a **V**, pointing up the dip, the sides of the **V** making angles of about 30° with the ribs. The timbers are carefully scored and hewed before being placed. In the bottom hitches a layer of fine manure and dirt is placed as a bedding for the first layer of timbers. The planking is placed vertically, a minimum num-

^a 1.5 represents diameter of props, 18 inches.

^b 0.5 represents 6-inch clearance.

ber of nails being used for fastening. Vertical buttress and horizontal timbers are placed as indicated in figure 10, A or B.

In this form of construction it is at times highly desirable to provide the "screener" and the gob-wall filter mentioned above.

Masonry, rather than timber, can be used for this form of construction. If masonry (fig. 11) is employed instead of timber, the form of the bulkhead is that of a full-struck arch, a semicircle with a radius

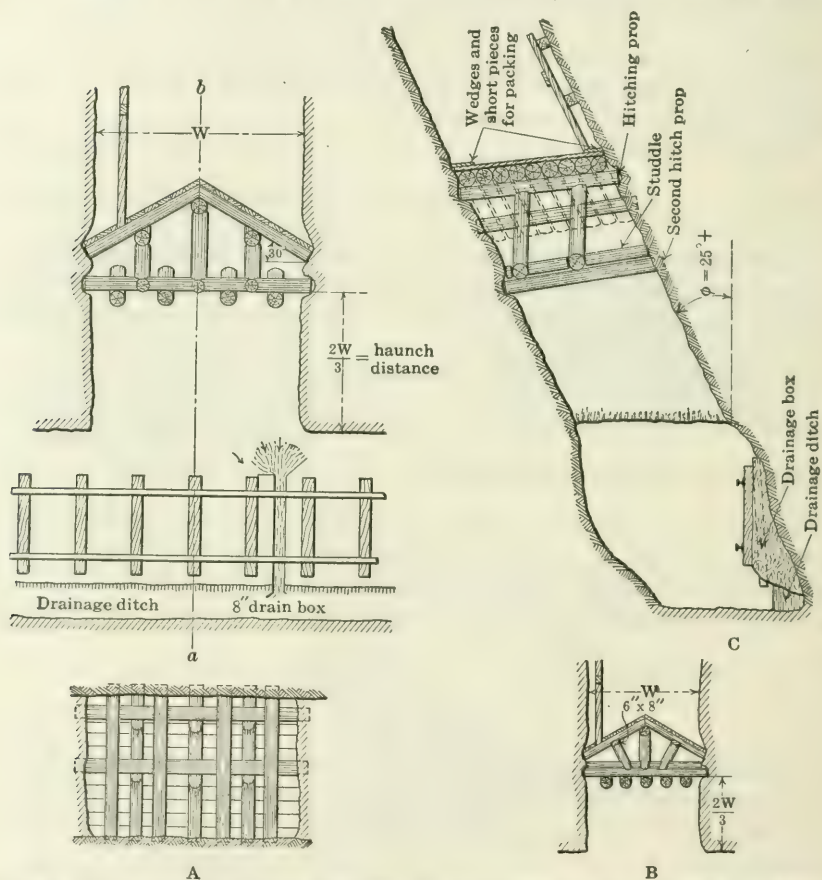


FIGURE 10. -Bulkhead for pitch workings. A, plan view and front elevation; B, plan view of modification of bulkhead shown in A; C, side elevation at ab .

equal to the width of the opening; the thickness of the bulkhead at the haunches is equal to one-third of the height and at the crown to one-sixth of the height. Drainage troughs (fig. 11) must be provided.

Under special conditions dry walls are in places used in conjunction with the timber construction. It is impractical to formulate any general rules for using such walls. However, it is safe to state that wherever the inclination of the coal bed is over 18 degrees dry walls are invariably constructed if rock is available. Great faith is placed in this type of bulkhead. The specific purpose of the dry wall is to

act as a breakwater or cushion and a partial filter, thus relieving the bulkhead of a portion of the direct hydrostatic pressure.

The use of rock^a blasted from the roof and floor for bulkhead construction was no doubt suggested by encountering the natural bulkheads formed by the many roof falls in old workings and the percentage of filling represented by the fallen rock. It may be possible to work out a practical application of blasted rock when the cost of other material for bulkheads becomes prohibitory.

Concrete bulkheads have been tried in several mines, and although their first cost is high they prove fairly economical in pitching beds

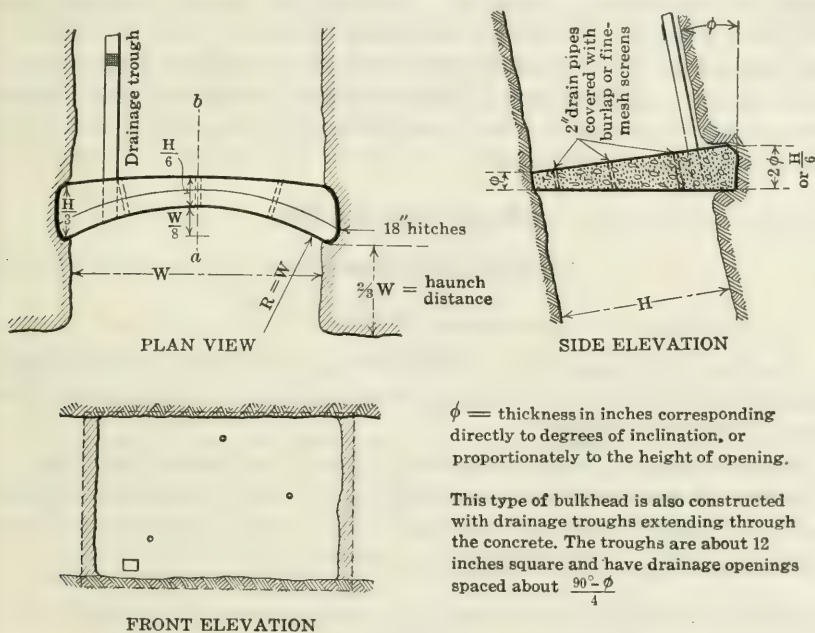


FIGURE 11.—Concrete or brick bulkhead for pitch workings.

where the bulkheads are subjected to great pressures and where the necessary timber would be very expensive.

This form of bulkhead construction is more frequently used where hydraulic filling is planned as a feature of the development of the mine. The bulkheads are constructed with trap doors so as to allow their use in conducting ventilation and in mine inspection in addition to their ultimate use as filler containers. The trap doors also permit traveling by workmen and officials before filling starts. After second mining has been started the bulkheads are of service as anchorages for new bulkheads for filling the opening on the mining side of a pillar.

^a Griffith, William, and Conner, E. T., Mining conditions under the city of Scranton, Pa.: Bull. 25, Bureau of Mines, 1912, p. 57.

With concrete bulkheads great care must be exercised to insure drainage by means of troughs.

Brick and stone bulkheads are seldom used. The remarks under concrete bulkheads are equally applicable to bulkheads of these types.

Concrete and other types of masonry construction possess unusual advantages when rehydraulicking is undertaken, especially in flat and to a large extent in chute workings. Second filling in any section of a mine is not undertaken until pillar mining, either partial or total, has been completed in that section. Timber bulkheads seldom last until second filling is begun, consequently the rib anchorage, either on one or both sides, is practically useless at the time of second filling, so that a quantity of valuable coal must be left as "anchor stumps" for anchorage for new bulkheads required in filling the openings made by mining the pillars. This objectionable feature is eliminated by masonry types, which allow a satisfactory connection or anchorage directly to the old bulkhead.

COST OF BULKHEADS.

PLANK-AND-TIMBER TYPE.

FLAT WORKINGS.

The cost of a given type of bulkhead depends largely on the amount of coal or roof that has fallen and the character of the coal and rock at the point of location.

Assume that a timber-and-plank type of bulkhead for filling a chamber 24 feet wide by 6 feet high is to be built in flat workings, with roof and floor of medium hard sandy shale. The itemized cost of construction is approximately as follows:

Itemized statement of cost of building a timber-and-plank bulkhead for flat workings.

MATERIAL.

Seven 6-inch props 7 feet long, at \$6.50 per ton-----	\$2. 00
350 feet 2-inch plank, at \$25 per M-----	8. 00
Nails and spikes -----	. 35
Burlap or brattice-cloth drainage-hole coverings-----	. 35
	\$10. 70

LABOR.

Cleaning and preparing bulkhead location, 2 men, one-half day-----	3. 00
Cutting hitches (top, bottom, and sides), 2 men, 1 day---	6. 00
Cutting, setting, and wedging props, 2 men, 2 days-----	12. 00
Planking and patching, 2 men, 1½ days-----	9. 00
Portage of material (approximately)-----	5. 00
	35. 00
Total-----	45. 70

For hard sandstone roof and bottom, other conditions being the same, there will be an additional labor cost for cutting hitches. This work necessitates moiling, and its cost will amount to at least three times that given above, or \$18. Therefore in sandstone, flat workings, the total cost of such bulkhead would be \$45.70 plus \$18, or \$63.70.

CHUTE WORKINGS.

In chute workings with medium hard, sandy-shale roof and bottom the cost of construction will be decidedly greater, as indicated below.

From the formula $S = \frac{2W}{3H}$, the props should be spaced 2 feet 9 inches apart, center to center; therefore the bottom hitches would be of the box type and the top hitches of the continuous or sliding type. By the formula $N = \frac{W}{S} + 1$, the number of props is 10. By the formula $D = \frac{3L}{2}$, the diameter of the props is 9 inches. The itemized cost of the bulkhead would be approximately as follows:

Itemized statement of cost of building a timber-and-plank bulkhead for chute workings.

MATERIAL.

Ten props 9 inches in diameter by 7½ feet long (12-inch bottom hitch, 6-inch top hitch).....	\$3. 00
350 feet plank.....	8. 00
Nails and spikes.....	. 35
Burlap or brattice cloth.....	. 75
1,200 feet 1-inch boards for drainage troughs.....	30. 00
	\$42. 10

LABOR.

Cleaning and preparing bulkhead location.....	3. 00
Cutting hitches (top, bottom, and sides).....	9. 00
Cutting, setting, and wedging props.....	18. 00
Planking and patching.....	9. 00
Portage of material.....	8. 00
Building 24-inch dry-wall filter.....	15. 00
Carpentry (drainage trough).....	12. 00
	74. 00
Total.....	116. 10

For hard sandstone roof and bottom, other conditions being the same, the cost of labor for cutting the hitches will be about three times that given above, or \$27; therefore the total cost of a bulkhead in chute workings with such roof and floor would be \$116.10 plus \$18, or \$134.10.

PITCH WORKINGS.

In pitch workings, the floor and roof being medium-hard sandy shale, the cost of construction would, of course, be higher than in flat or chute workings. By the formula $S = \frac{4W}{7H}$, the spacing of the props would be 2.3 feet. The props should, therefore, be spaced not over 26 inches apart, center to center. From the formula $N = \frac{W}{S} + 1$, the number of props required would be 12. The diameter of the props, determined from the formula $D = \frac{7L}{4}$, would be 10.5, or say 11 inches. The clearance distance between props ($S - D$) would be 15 inches; therefore to avoid expensive cutting in hard sandstone the bottom hitches should be of the box type and only the top hitches of the trough or sliding box type. The cost of the bulkhead would be approximately as follows:

Itemized statement of cost of building a timber-and-plank bulkhead for pitch workings.

MATERIAL.

Twelve props, 11 inches in diameter by $7\frac{1}{2}$ feet long (12-inch bottom hitch, 6-inch top hitch)-----	\$13. 00
350 feet 2-inch plank and patching-----	8. 00
Nails, spikes, burlap, etc-----	2. 00
Boards for drainage troughs-----	30. 00
	\$53. 00

LABOR.

Cleaning and preparing bulkhead location-----	5. 50
Cutting hitches (top, bottom, and sides)-----	15. 00
Cutting, setting, and wedging props-----	23. 00
Planking and patching-----	12. 00
Constructing and placing drainage trough-----	12. 00
Building dry-wall filter and manure curtain-----	18. 00
Portage of material-----	20. 00
	105. 50
Total-----	158. 50

For hard sandstone roof and bottom the cost of labor for cutting the hitches, moiling being necessary, will be approximately three times that given above, or \$45; therefore the total cost of a bulkhead in pitch workings with sandstone roof and floor would be \$158.50 plus \$30, or \$188.50.

If the bulkhead being considered were of the inverted-V type, the cost of construction would be approximately as follows:

Itemized statement of cost of building a timber-and-plank bulkhead of the inverted-V type.

MATERIAL.

33 timbers, 12 inches in diameter by 16 feet long-----	\$52.00
Other material same as itemized above-----	40.00
	----- \$92.00

LABOR.

Cleaning and preparing bulkhead location-----	6.00
Cutting hitches-----	21.00
Cutting, scoring, and placing timbers-----	66.00
Planking, wedging, troughing, etc-----	42.00
Portage of material-----	28.00
	----- 163.00
Total-----	255.00

For hard sandstone roof and bottom an additional cost of \$42 should be added, making the total cost \$297.

CONCRETE TYPE.

The cost of a concrete bulkhead for use in filling the chamber referred to above (24 feet wide by 6 feet high) would be \$52 for material and \$173 for labor, a total of \$225, if the roof and the floor were of medium-hard sandy shale.

For hard sandstone roof and floor an additional cost of \$68 should be added, making a total of \$293.

COMPARISON OF VARIOUS TYPES OF BULKHEADS.

TIMBER BULKHEADS.

In comparing the advantages of the various types of bulkhead construction, the ease with which timber for timber bulkheads can be transported over caved and broken ground is an important factor favoring that type, as is the comparatively low cost of timber construction and its flexibility and advantageous application under difficult conditions. In timber construction, however, it is impossible to anticipate the reuse of materials employed.

MASONRY BULKHEADS.

Masonry construction is necessarily expensive. For extensive final or pillar mining the masonry type of bulkhead possesses attractive advantages and may in future work be developed so as to present

the greatest ultimate economy. Heretofore such constructions have been built primarily for ventilating purposes, being later used advantageously in mine filling.

BLASTED-ROCK BULKHEADS.

Bulkheads made by blasting the roof and floor are an extension of the plan of supporting the roof in this way.^a With a considerable quantity of small coal and fine dirt available it may be possible to construct a barrier of blasted rock across a comparatively flat working place and, by placing a sufficient quantity of this fine material at the inner face of the rock barrier, to form a filter that will eventually retain the filler. Judging from the apparent effectiveness of general roof falls as bulkheads, this type of construction should be efficacious and economical in sections considered inaccessible as regards the construction of either timber or masonry bulkheads, especially in places where the roof and bottom are softer than the usual sandstone of the anthracite mines and where the opening is less than 6 feet high. Air and water cause newly broken-down shales and "slates" to slack or disintegrate, consequently the voids or interstices in such a bulkhead rapidly fill up and the barrier becomes less pervious.

BRICK AND OTHER MASONRY BULKHEADS.

Brick, concrete, and other masonry bulkheads are the most expensive, but can be made to serve a double use, as ventilation stoppings and subsequently as filler bulkheads. In many mines where the workings are extensive it is necessary to construct stoppings of masonry to insure a sufficient quantity of air reaching the working faces. Bulkheads of masonry are most practical when filling is conducted on the panel or district system. In such practice each panel or district is separated by building bulkheads across openings in the boundaries only; no bulkheads are constructed at the foot of chambers or rooms. Timber bulkheads would be impracticable, owing to the long interval between the first mining and the time when filling can be safely undertaken.

FILLING DIFFERENT CLASSES OF WORKINGS.

As previously stated, hydraulic mine filling originated in connection with the solving of special problems under the stress of emergency. The initial efforts were naturally conducted along experimental and inefficient lines; improvements in method were developed as time for observation elapsed and results could be care-

^a Griffith, William, and Conner, E. T., Mining conditions under the city of Scranton, Pa.: Bull. 25, Bureau of Mines, 1912, p. 57.

fully studied. Since the first attempts at mine filling, in which the flow of the filler was unrestricted and in which it was impossible to estimate where the filler was being deposited and whether it was accomplishing the desired results, rapid improvement has been made. In the past many large areas of mine workings were made entirely inaccessible by the filler blocking the only open places leading to the district to be filled. These effects led to attempts (1) to control the flow of the filler, and (2) to confine the filler within predetermined limits. Through gradual development the methods now extensively employed both in this country and abroad came into use. To-day hydraulic filling has wide application and is, under certain conditions, an important and indispensable aid in the mining of coal.

CLASSIFICATION OF SYSTEMS AS TO AREA TO BE FILLED.

If the area to be filled be taken as the basis of classification, all systems of hydraulic mine filling may be divided into three groups, as follows: Individual, panel, and collective.

In the individual system of filling the filler is discharged directly into each chamber or breast to be filled. This system is generally adopted in flat workings for either total or partial filling. In the panel system the filler is discharged into groups of chambers or breasts, one or more chambers or breasts being left unfilled. This system is generally adopted for partial filling in flat, chute, or pitch workings. In the collective system the filler is discharged at the highest accessible elevation in a given section of the mine and is allowed to flow unrestrictedly into all the chambers or breasts to be filled in that section. This system is adopted for total filling in chute or pitch workings.

CHOICE OF SYSTEM ACCORDING TO AREA TO BE FILLED.

The determination of the most desirable system of filling is dependent on the proposed future operation, the time to elapse between filling and pillar mining, and the ultimate pillar extraction and possible refilling. If the interval between filling and reopening is to be comparatively short, a relatively short-lived material may be used in constructing the bulkheads; for example, if reopening is to be undertaken within one year's time, oak props and hardwood plank will prove efficient and economical, and in refilling, the new bulkheads can be satisfactorily anchored to the old bulkheads. If the interval is to be longer, more durable wood—for instance, pine props and hemlock or pine planks—should be employed.

The method of reopening filled areas should be determined by the inclination of the workings. If the bed is flat, the gangway and airway are generally maintained; therefore the filling should be con-

ducted so as to require the least quantity of material to be rehandled, especially where only a partial recovery of pillars can be undertaken.

If the workings are inclined over 25° , the collective system is the most practical and economical, because, although bulkheads of heavy construction and consequent high cost will be required, comparatively few bulkheads will be necessary. Also, as the reopening of such workings consists in driving a road along the high rib of the old gangway, the least amount of pillar coal is isolated, and the maximum recovery is possible at the least expense in rehandling filler. In fact, with this system the immediate availability of a large quantity of coal somewhat compensates for the high expense incurred.

In flat workings, if the greater part or all of the pillar coal is ultimately to be extracted, the collective system possesses a great advantage over the individual or panel system, as the only bulkheads necessary are those provided for ventilation and for entrance and exit for haulage. However, in mines generating inflammable gas the panel system is the only one to be recommended, as this system allows free circulation of the ventilating current around the filled district at all times and thereby guards against dangerous accumulations of such gas.

Collective filling is the least expensive system, panel filling ranks next, and individual filling is the most expensive system.

In any form of filling, whether individual, panel, or collective, it is important to guard against the dangers of overflows or "rushes." These are frequently caused by piles of gob and dirt or by falls of roof. The water and the filler accumulate behind such obstructions until an overflow or break occurs. Then the onrushing mass often breaks bulkheads or blocks airways, haulage ways, and manways.

CLASSIFICATION OF SYSTEMS AS TO CHARACTER OF THE WORKINGS.

If the character of the workings be taken as a basis for classification, hydraulic mine-filling systems may be divided into four groups, namely: Surface openings, flat workings, chute workings, and pitch workings.

SURFACE FILLING.

The first group may be made to include all manner of filling conducted outside of the mines, whether for the purpose of grading or storing refuse. Strictly speaking, such filling is not usually done by a hydraulic process. The filler is dumped from wagons or cars in certain locations, either as spoil banks or for temporary storage.

The simplest form of surface filling consists in depositing material, either by the hydraulic method or in a dry state, in such cavities as are caused by mine caves or by "crop falls." All such filling is done

directly from the outside and as a rule is undertaken only where the surface is improved by residences, shops, or public or industrial buildings.

In this connection it is well to bear in mind that a mine cave is caused by the removal or the robbing of pillars or the failure or crushing of pillars owing to a squeeze, and the resulting surface subsidence may be either uniform or intermittent.

Another use of surface filling, usually hydraulic, is for improving the topography at a colliery by filling small gulleys, depressions, washouts or even marsh lands. The advantage of such filling is readily appreciated by those who have had experience with colliery operations in rolling or swamp land.

Hydraulic filling has not yet become general throughout the entire anthracite region and unfortunately there still exist practices long since proven inconsistent with progress; these practices no doubt account for much of the highly regrettable pollution of the streams, sometimes unintentional and at other times willful. A remedy for such conditions should be eagerly sought and adopted. Unintentional stream pollution results from the erosion, by heavy rains, of culm temporarily or permanently placed upon steep watersheds, or the washing away of large spoil banks so placed as not to be beyond the limits of flood waters.^a In many instances culm and other mine refuse have been placed in large piles at points close to breakers or washeries for the express purpose of temporary storage pending recovery and shipment of small sizes of coal. Within the last decade anthracite practice has been improved to meet a steadily widening market for the small sizes, millions of tons of which had for many years been stored in huge piles and had been considered as practically waste. In the reclamation of these piles, there is left as refuse only such culm as will pass through a screen with openings of three thirty-seconds of an inch, or in some instances of three sixty-fourths of an inch.

The fine refuse embraced in the coal loss is deposited on the surface or is hydraulicked into the mine workings. If it is deposited on the surface by the hydraulic method, the usual practice requires that a timber-and-dirt dam be constructed to contain it, or that the depressed area be inclosed by a bank of rock or breaker refuse. When the material has been deposited the height of the reservoir walls can be increased 3 or 4 feet by banking up the deposited material. The water draining from the filler may be collected at some convenient point and re-used in the breaker or washery or allowed to run off.

^a Report of Pennsylvania commission appointed to investigate the waste of coal mining with the view to the utilization of the waste, 1893, p. 134.

FILLING FLAT WORKINGS.

Hydraulic mine filling in flat workings, or workings of less than 10 degrees inclination, is the most difficult to perform, and is the most expensive. Filling in such workings must be done almost entirely by the use of pipes; therefore great care must be exercised to provide a supply of water at all times sufficient to transport the material through the pipe lines. The official in charge should possess some knowledge of the working principles of hydraulics. The proper size of the transport pipes should receive special study. For example, if the amount of material to be hydraulicked is less than 200 cubic yards per day of 9 hours, and if the cost of handling water is comparatively high, it may be possible to economize on the quantity of water and to conduct satisfactory filling with 4-inch pipe, especially if the pipe line is required to conform to an irregular profile and if the mean effective hydraulic head is high enough to keep the pipe line clear. For lower mean effective hydraulic head, for a larger quantity of material, and for varying grades obviously a pipe of larger diameter, say 6 or 8 inches, must be used.

To avoid blockages, it is essential to maintain the pipe line so that the filler will flow through at the greatest possible velocity. A good practice is to allow the water to flow through the pipe line for at least 10 minutes before the filler is introduced and for a sufficient time at the close of a day's operations to insure all filler being out of the line.

WATER REQUIRED.

It is obvious that the quantity of water required is dependent on the mean effective hydraulic head; the proportion of water varies from 50 to 90 per cent, depending on the grade of the line and the nature of the filling material. Naturally the steeper the grade the less water is required. In general practice the proportion of water approximates 90 per cent of the total volume passing through the line.^a

DISTRIBUTION OF FILLER.

One of the most essential conditions in hydraulic mine filling, especially in filling flat workings, is absolute control of the flow until the filler reaches the desired point of deposit. Good practice requires that the pipe line be laid to this point, no allowance being made for flow in the chambers. This method will guard against the dangers of "rushes," with a consequent possible loss of output or life if the filling is being conducted in workings on a "live" lift

^a Wilson, H. M., *Irrigation engineering*, revised edition, 1910, pp. 61-69, 338-344.

or level. Further, the most successful filling is obtained by systematically changing the discharge into different districts. This is accomplished by constructing branch pipe lines into different sections of the mine workings previously prepared to receive the filling material, so that it will be possible to divert the flow from one section to another at stated intervals or upon short notice. The practice of continuous filling in one section is to be discouraged, as the best results are obtained only by allowing from 15 to 18 hours to elapse after 200 to 400 cubic yards has been deposited, so that proper seepage can take place before another quantity is deposited.

To allow for refilling or supplementary filling, a period of two weeks should elapse before the filler pipe line is withdrawn from any section considered filled by the first filling. The filler will shrink from 1 to 10 per cent during the seeping period. (Pl. I.)

In all horizontal places or places of low dip overflow or "telltale" pipes should be so placed as to indicate by discharge when the filler deposited has reached the roof at the highest point in those places.

LABOR REQUIRED.

The working force necessary satisfactorily to operate the filler line is, roughly speaking, one man for the surface, one man to patrol each 1,000-foot length of operating pipe line, and one man to inspect pipe discharge, filler deposit, and seepage. The underground force can also look after the drainage watercourses leading to the sump.

VENTILATION.

The proper ventilation of mine workings while being filled requires more attention than is usually accorded that feature. Ventilation is especially important in mines where explosive gases are generated. If filling is conducted on the individual system, means for allowing the escape of air from behind the bulkheads should be provided, thus preventing dangerous accumulations of explosive gases. Means should also be provided for carrying away the heat and moisture usually given off during the shrinkage of filler consisting of anthracite culm. Where excessive amounts of dangerous gases are evolved it is advisable to conduct filling on the panel system so as to permit circulation of air around the entire area to be filled. If none of the above precautions is practicable it may be possible to extend the drainage troughs in such a manner that they can be utilized for ventilation purposes. Direct connection may be made to the return air course or to a split air current either on the return or the intake side. A "booster" fan driven by steam, compressed air, or electricity has been found very serviceable.

SEEPAGE.

The drainage of the seepage water from the filling material deposited requires careful attention so that the least possible amount of filler shall be carried away in suspension. The very fine material, called sludge, that escapes from the deposited mass generally consists of the particles essential to perfect cementation. Great care should be exercised to retain the sludge in the body of the mass, instead of allowing it to seep out and cause troublesome accumulations in the main sumps. Proper seepage will not take place if the filler is deposited continuously or at frequent intervals, but it is obtained to a satisfactory degree if filler is deposited only during periods not exceeding four hours.

GENERAL REMARKS.

As previously stated, the practice of filling flat workings by continuous flow should be discouraged for several reasons. The most important of these are: (1) The filling is incomplete both horizontally and vertically; (2) the workings can not be properly ventilated while filling is in progress; and (3) improper seepage takes place. These objections are eliminated to a great extent by using either the individual or the panel system previously described.

There is opportunity for general improvement of the present system of preparing mine workings for filling. The change most essential is in the manner of opening chambers and of driving crosscuts. New chambers should be opened as narrow as possible, allowing only sufficient room for ventilation and necessary car clearance. The opening width of the room neck might be reduced, for a distance equal to the width of the opening, to about two-thirds that of the regulation width of chamber, thereby decreasing the cost of bulkhead construction by at least one-third and providing better conditions for reopening.

FILLING CHUTE WORKINGS.

Chute workings—that is, workings where the inclination ranges between 10° and 25° —as a rule are free from gas accumulations except along the axis of an anticline; therefore, the danger from gas is practically negligible and the panel system may be discarded for either the individual or the collective system, depending on the degree of efficiency desired. The comparative advantage in cost lies in the smaller number of bulkheads required and the great saving in pipes or troughs.



A. GANGWAY CUT THROUGH CULM FLUSHING, OXFORD MINE.



B. GANGWAY CUT THROUGH FLUSHING, CULM STANDING AS A VERTICAL SELF-SUSTAINING WALL, OXFORD MINE.

WATER REQUIRED.

Considerably less water is required in chute workings than in flat workings to carry the filler to the point of deposit. In many mines a proportion of water as low as 60 per cent is sufficient if the profile is not too irregular and the mean effective hydraulic head is comparatively high.

DISTRIBUTION OF FILLER.

In the distribution of filler the usual practice is to construct a pipe line along the airway of the gangway or lift next higher than the section to be filled (fig. 12, lines A, B, C, D, and E), or if there is an impregnable chain pillar between the chamber faces and the next higher lift or level, the pipe line is led through the headings or cross-cuts at the face of the chamber of the filling lift. If the section to be filled consists of more than five chambers, T connections with valves are placed at intervals of five chambers, for instance, at the third, eighth, thirteenth, etc. (fig. 12, line A), the pipe line being made long enough to supply at least three groups of five chambers each. When filling is started and the number of chambers ready to receive the filler is greater than 15 the filler may be conducted from the various connections for half-shift periods. In the case of the workings shown in figure 12 the extreme inside section (chamber 13) and the adjoining section (chamber 8) should preferably receive filler the first day. The following day filler should be placed in the extreme outside (chamber 3) and the second adjoining section (chamber 13), and so on. This shifting allows each section to drain for 20 or more hours before filler is again deposited in it. The filler may be discharged from the T connection at the face of the chamber and a ditch or channel through the loose dirt may be dug by shovel all the way to the bulkheads, thus saving the cost of pipe or trough. Under such conditions it is possible in the individual or panel systems to fill fairly satisfactorily five chambers from the bulkheads to the point of discharge. Complete filling, or refilling after seepage from first filling has stopped, can be done, after all chambers have been filled as previously outlined, by having the pipe line discharge at the highest point in the entrance to that section (five chambers), bearing in mind the necessity of recovering all the pipe in that section.

If the collective system is employed and another section is not available for filling, the pipe line should be so constructed as to permit the discharge of filler at intervals of 10 chambers, the first point of discharge being at the fifth chamber in, the second point of discharge at the fifteenth chamber in, and so on.

The filler shrinks considerably during the seeping period, and to permit refilling or supplementary filling a period of two weeks

should elapse before the filler pipe line is withdrawn from any section considered filled by the first filling.

In figure 12 the figures along the pipe lines A, B, etc., refer to the mining periods, the figures 1, 1, 1, etc., referring to the first mining, 2, 2, 2 to second, etc. The arrows indicate the direction of the mining.

LABOR REQUIRED.

The working force for operating the filler line for chute workings generally consists of one man on the surface, one man to patrol each 1,500 feet of operating line, and one man to direct the pipe discharge, the chamber flow, the deposit of filler, and the seepage. The underground force also looks after the drainage water courses.

VENTILATION.

If pillar mining is to follow the filling of chambers, it is advisable to utilize the inside or line chamber and the airways to the gangway as air courses. This can be done by constructing bulkheads in the crosscuts between the two chambers farthest in and between the gangway and the airway. The general practice is to maintain the gangway and the airway as intakes and the inside or line chamber as the return-air course of all lifts. The volume of air passed should be sufficient to carry off gas and keep the temperature from rising too high.

SEEPAGE.

Careful attention should be given to the character of the seepage. This will depend on the construction of the bulkheads and the system of depositing the filler. It should be borne in mind that the fine particles often carried away in suspension in the run-off water are very necessary for the most efficient cementation of the filler and should be retained therein. Rivulets or freely flowing streams should be guarded against, as they are the surest source of breaks or leaks in bulkheads. The ends of drainage troughs should be provided with strainers made of brattice cloth or canvas.

GENERAL REMARKS.

The general remarks under the section entitled "Filling Flat Workings" apply equally to the filling of chute workings, except that in chute workings filling by unrestricted flow is decidedly more efficient than in flat workings, but the practicability of its adoption under any given conditions should be established by careful study.



 CULM FILLER
 ROCK AND-CULM FILLER
 HYDRAULIC-FILLING LINE
 DRAINAGE-COLUMN LINE

PAGE III. Distribution of filler and filler lines in a mine.
 72171. Bull. 69. 13. (To face page 62.)

FILLING PITCH WORKINGS.

The hydraulic filling of workings in which the inclination exceeds 25° is less difficult than that of flat or chute workings and the method of depositing the material is much less expensive. Fewer bulkheads need be constructed and less attention to chamber flow is required. The most satisfactory system of mine filling is that which allows inspection from the point of introduction to the point of discharge. This is possible where shafts or slopes form the connection between the mine workings and the surface. When the filler is introduced through crop falls or cave holes and is allowed to flow by gravity it will be unconfined and neither the places where it is being deposited nor the solidity of the filling will be known. The practice should be discouraged.

WATER REQUIRED.

When the workings are comparatively open the quantity of water required varies from 40 to 90 per cent of the total volume.

DISTRIBUTION OF FILLER.

The distribution of the filler may be accomplished by means of pipes and pressure in flat parts of the workings and by means of troughs in inclined places. The pipes may be of wood, wrought iron, cast iron, or steel, with various modifications. The troughs may consist of ordinary boards or planks nailed together, usually in the shape of a V, or of half-round terra-cotta or cast-iron sections. Sheet-iron plates bent square, hexagonal, V shape, or half round have been successfully employed. The use of troughs is neither popular nor economical unless the grade is rather steep—that is, greater than 10° —and a large quantity of water is available.

The general practice is to conduct all filler through metal or wooden pipe to the point of discharge in the chambers, the distribution being generally the same as that previously outlined for chute workings. The filler may be conducted through mine workings in wood, metal, or earthen troughs if there is no ascending grade in the line. Filler has been conducted along old drainage ditches and through chambers to desired sections with considerable success. Usually only such bulkheads are constructed as are necessary to confine the district and to provide proper openings for ventilation and drainage for other parts of the mine as well as for the district being filled.

The collective and panel systems are used almost exclusively. The choice between these systems is dependent on the physical condition of the workings. Mine filling as a rule is not undertaken until a

comparatively long time has elapsed after the first mining, and consequently many large areas of workings may be practically inaccessible on account of falls, caves, or squeezes. Under such conditions it is necessary to introduce the filler in such manner as will insure the most efficient distribution and filling. It is therefore advisable to have several points of discharge in a district, and thereby increase the possibilities of completely filling around the falls and caves. For filling under such conditions considerably larger quantities of water are required than are necessary under ordinary conditions.

If possible, filling should start in the lowest lifts and progress toward the higher workings. Where final filling, or filling after the pillars have been mined, is conducted, the final step in filling a given section of the mine should be the filling of the air course.

LABOR REQUIRED.

The working force necessary to operate a filler line under the difficulties of pitch workings should be approximately as follows: One man to attend to the surface arrangement, one patrolman for every 1,000 feet of line (two men, if troughs are used), at least two men to direct the flow of the filler in the chambers, and one man to look after the drainage water flowing from the bulkheads to the sump. The man looking after the drainage may be placed in charge of the filling operations.

VENTILATION.

In pitch workings where inflammable gases are generated, and where pillar mining is to follow the filling, it is a safe practice to maintain one of the chambers as an air course despite the general tendency of the inflammable gases to accumulate at the higher elevations. The air course may be established by constructing substantial bulkheads in crosscuts and other openings connecting with the permanent air courses.

SEEPAGE.

The question of seepage under conditions encountered in pitch workings is of the greatest importance and demands careful study and consideration. The first consideration should be the thorough draining off of water after the filler has been deposited. The most satisfactory method is by means of draining troughs with strainers, as previously described. If proper seepage is thus insured, excessive pressures due to the hydrostatic head of the plastic mass, which endanger the stability of the bulkheads and may endanger the lives of the workmen in lower levels, are avoided. Proper seepage, including the prevention of loss of fine particles, will insure perfect cementation of the filler, thereby insuring the greatest supporting value. Such cementation is especially important in order that the

sliding or swinging tendency of the overlying burden may be avoided when pillar mining, either by slabbing or splitting, is undertaken.

The drainage water from the filler should be conducted along abandoned haulage ways, or airways, or through old chambers, to the permanent sump. If this is impracticable, the drainage water may possibly be collected at some convenient point outside of the place of deposit, and be conducted in pipes down the pitch, and if necessary, a considerable distance upgrade to the regular or permanent sump. This will avoid serious erosion along traveling ways and haulage ways, and guard against possible large accumulations of water which might be a source of considerable damage.

GENERAL REMARKS.

The general remarks under the section entitled "Filling Chute Workings" are applicable to "pitch" workings. A special caution should be observed, however, in the adoption of unrestricted filler flow. This is particularly dangerous when the filler has been deposited in a chamber from the bulkhead in the first crosscut to the adjoining vacant chamber. In the crosscuts, as a rule, temporary wooden stoppings are constructed for the control of the ventilation current; frequently the crosscuts are partly blocked with "chipping" coal or with small falls of roof. The stoppings or blockages may cause the filler to accumulate and the hydrostatic pressure, as soon as it becomes great enough, may cause the mass to break through, rush down the vacant chamber, and strike the bulkhead with great force, disastrously affecting the operation of the mine and even causing loss of life among workmen in the lower levels.

Sedimentation of the filler in pitch workings is practically perfect. The filler is usually deposited so compactly as to make refilling or supplementary filling practically unnecessary until pillar mining is undertaken.

EFFECT OF HYDRAULIC MINE FILLING ON VENTILATION AND DRAINAGE.

The ventilation and the drainage of a mine are directly influenced by the filling. The entire ventilation is improved by the general filling of old workings. In unfilled workings air stoppings, if made of wood, rot and become leaky, the constant partial combustion of carbonaceous matter evolves considerable carbon dioxide gas, and the coal itself takes up oxygen. Such conditions are highly objectionable. Furthermore, through the filling of chambers and entries the frictional resistance to the air current may be greatly diminished, thus allowing, with the same water gage, a much larger quantity of air to be circulated through the mine; provided, of

course, that the main upcast or downcast is of larger cross-sectional area than the main mine air course. The ventilating pressure necessary is considerably decreased by the filling of the "dip" workings.

The drainage of a mine is often seriously affected by the introduction of mine filling. Water courses must be changed so as to obtain steeper grades, or the water must be piped, because the increased proportion of solids carried in suspension causes frequent accumulations that threaten the flooding of haulage roads or pumping stations. Special provision must be made to intercept and to remove as much sediment from the water as is possible before it enters the sump (fig. 13, detail sections). In most instances the introduction of hydraulic mine filling requires additional pumping facilities. If the water contains acids, special wood or cement lined pipes and pump parts are required. On the other hand, when an inadequate pumping plant is replaced by one of the requisite capacity, the total cost of handling the mine water is often materially reduced.

PREVENTION OF ACCUMULATIONS OF GAS AND DUST.

Next to the reclamation of coal in pillars probably the greatest advantage that can be claimed in favor of mine filling is the resulting prevention of dangerous accumulations of gas and dust in the dry old workings of a mine where such accumulations may seriously jeopardize its safe operation.

Accumulations of inflammable gas in whatever quantity are dreaded by all miners. It is serious enough when such accumulations occur in readily accessible places, but to have them occur in old workings, practically inaccessible on account of falls and caves, is a cause of deep concern to every mine worker and official. By careful management serious accumulations have been removed by displacement with filler in mines where removal by ventilation would have entailed enormous expense in clearing caves and in reconstructing air courses. The removal of such accumulations is not an easy matter under favorable circumstances, especially when the gas mixture has been stagnant for some time and partial stratification has taken place. Numerous explosions of gas have resulted from accumulations in unsuspected places as a result of falls of roof or caves blocking the air currents or causing permanent stoppings to leak, and to short circuit the air current, thereby causing insufficient air to reach the working places or the faces of the air courses.

Accumulations of fine inflammable coal dust are to be guarded against as dangerous. Mine filling serves to reduce to a minimum the dust-collecting surfaces in old workings. Accumulations of dust are liable to become active propagating agencies in the event of an explosion, so that any practicable method of eliminating this danger is desirable.

GREATER HUMIDITY OF MINE ATMOSPHERE.

In the process of hydraulic filling a perceptible rise in the temperature of the surrounding atmosphere has been noted, particularly where iron pyrite was present in the filler. Although such generation of heat at first caused considerable alarm as possibly indicating a fire, experience has demonstrated that it has a beneficial result. Owing to the rise in temperature from the heat developed by the iron pyrite or other oxidizable material, the humidity of the air is increased. The moisture taken up by the air is condensed in cooler parts of the mine, and helps to keep the dust there from becoming dry.

Practically the only gases caused by mine filling are carbon dioxide (black damp), carbon monoxide (white damp), and hydrogen sulphide (stink damp). In most mines the quantities are so small that they can not be detected by chemical analysis, and in general they may be said to be negligible.

DRAINAGE SYSTEM REQUIRED.

When hydraulic mine filling is practiced, a well-planned and well-equipped drainage system is essential. Not infrequently the amount of mine filling is restricted by the quantity of water the existing pumping equipment will handle. On a sound business basis, however, additional facilities should be provided, even though the cost may amount to thousands of dollars.

Drainage is considered under three headings, as follows: (1) Water-course to sump; (2) pumping equipment; and (3) sump cleaning.

WATERCOURSE TO SUMP.

The course along which the water draining from the filler must flow on its way to the main or an auxiliary sump should receive careful attention. The water should be so conducted as to offer the least hindrance or possibility of danger to the operation of the mine. Where there is a sufficient continuous grade, the water may be confined to ordinary mine-dirt or mine-rock channels. Where the grade is less, wood or terra-cotta troughs may be employed to advantage, particularly where blockage of the ditch or channel may cause serious accumulations of water and fine filler, which, when suddenly released, cause serious washouts or floods on traveling-ways or haulage-ways. To guard against such danger, wood pipe or secondhand metal column pipe may be used to conduct the water beyond points of probable blockage. Pipe is also used to conduct water across basins, "swamps," or other depressions.

Before the water enters the sump of the main or central pumping plant it should flow into and through a series of settling basins (A, fig. 13). By sedimentation a considerable part of the fine material

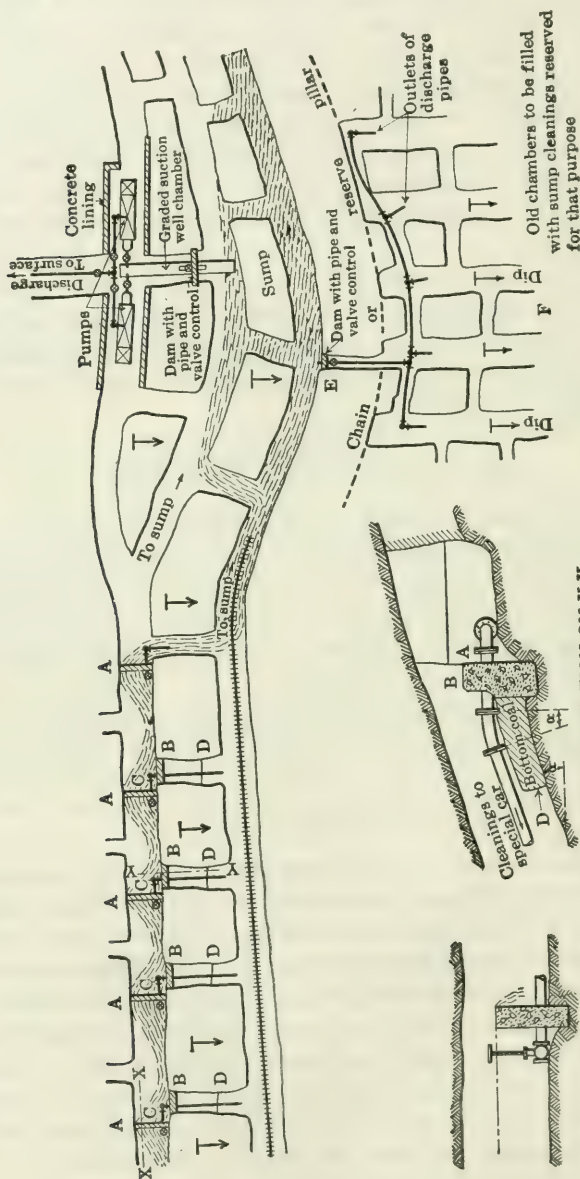


FIGURE 12.—Mine-drainage system.

still held in suspension by the water is eliminated. At intervals of inactivity the basins may be cleaned and the sludge loaded directly into cars, flushed into water-tight cars, or flushed into the mine workings on lower levels. The dams of the settling basins may be of

plank, stone, brick, or concrete. They usually are constructed so as to fill one-half of the opening along the lowest rib. This height allows cheap and convenient cleaning.

PUMPING EQUIPMENT.

If the lift to the surface is less than 500 or 600 feet from the main pump and the mine opening is not a shaft, the water-handling equipment generally consists of duplicate or triplicate units, either electrically driven or high-duty, triple-expansion, steam or compressed-air pumps located at the central drainage sump, generally near the foot of the shaft, slope, or water-discharge bore hole. There are also in use many steam-operated and a few electrically driven water hoists. The water ends of pumps and the tanks of water hoists are constructed of various acid-resisting metals. Pump valves and water barrels are also lined with cement and wood. Where comparatively little sediment is present in the sump water, the regular plunger type of pump is used. Where the water contains considerable sediment the piston type of pump is preferable.

SUMP CLEANING.

Sump cleaning always presents a serious problem and is generally expensive. Where the main central sump is located above the lowest working levels, cleaning is greatly simplified by driving a narrow opening through the chain pillar and constructing a substantial masonry dam in the opening (E, fig. 13). A 10-inch pipe with valve and blank flange should extend through the dam in the middle near the bottom. A pipe line may be laid to connect this pipe to vacant openings (F, fig. 13). When the sump needs cleaning, the accumulation of sludge is stirred by means of shovels or hoes, the blank flange is removed, the pipe line is connected, the valve is opened, and the entire sediment is easily and quickly flushed out. If the sump is so located as to make impracticable the method above outlined, a wooden track for mine cars is constructed to the lowest accessible point in the sump, and after the sump has been drained as much as possible, men shovel the sediment into cars, haul it to other parts of the mine, and unload it into old workings.

COST OF HYDRAULIC MINE FILLING.

The conditions under which hydraulic mine filling is conducted are extremely variable, and statements of cost must necessarily be prefaced with the remark that the geological and physical characteristics of a mine greatly influence and may determine the ultimate cost of filling its workings.

Folds and faults may make the slope of the filler pipe lines less than the hydraulic gradient, thus preventing filling by gravity and necessitating the pumping of the material. As a rule, the physical condition of old or practically abandoned mine workings considerably increases the cost of transporting materials and of constructing bulkheads and pipe lines. In the summaries presented below, the estimates given are based on the present cost of labor and materials in the anthracite region.

SURFACE TRANSPORTATION.

Hydraulic mine filling with culm commences at the breaker or washery, and therefore the detailed discussion of cost logically begins at that point.

Surface transportation may be divided into two general classes: (1) Gravity and (2) mechanical. In one the filler and water flow by gravity to the beginning of the intermediate system, in the other the filler and water are conveyed from some common point at the breaker or washery to the intermediate-transportation system by either pumps, elevators, scraper or conveyer lines, or cars.

The cost of surface transportation depends largely on local conditions. If the filler is only such refuse as results from screening and washing coal and will flow by gravity to the intermediate-transportation system, the cost will vary from 1 to $1\frac{1}{2}$ cents per cubic yard. If to the screenings and washery refuse, boiler ashes and crushed breaker rock are added, to the cost given must be added the cost of crushing, which, including running expenses and depreciation charge, varies from 3 to 4 cents per cubic yard, making the total cost of gravity transportation 4 to $5\frac{1}{2}$ cents per cubic yard.

If the refuse is conveyed by a conveyer or scraper line to dump cars and hauled in cars, an additional charge of $3\frac{1}{2}$ to $4\frac{1}{2}$ cents per cubic yard must be added to the above. If instead of being handled by the scraper or conveyer and the dump car, the filler is handled by pump through pipe lines not exceeding 500 feet in length, the total cost of transporting the filler to the intermediate-transportation system should not be greater than $2\frac{1}{2}$ to 4 cents per cubic yard.

The cost of transporting on the surface local sand, gravel, loam, and clay, none of which requires crushing, should not exceed 14 cents per cubic yard. The cost of transporting in large quantities local quarried material that can be handled by steam shovel and sluiced by gravity from the crusher to the intermediate-transportation system will be 30 to 40 cents per cubic yard. Such quarried material must be crushed so that all particles will pass through a $\frac{3}{4}$ -inch screen. If the crusher is at a considerable distance from the intermediate-transportation system, a charge of 0.4 cent per cubic yard for every 500

feet should be added. This charge provides for a man for patrolling every 500 feet of pipe or sluiceway.

The total cost in cents, C , may be expressed by the formula:

$$C = M + \left(\frac{D}{500} \times .4 \right),$$

in which M represents the cost in cents of the material as it comes from the crusher, and D represents the distance in feet from the crusher to the intermediate-transportation system.

The utilization of distant material, such as sand, gravel, loam, or crushed rock and slag, that might be brought by empty coal cars returning from points outside of the coal fields and convenient to the railroads, has been a much-discussed problem among able mine managers and mining engineers. The cost of the material at the source, the cost of loading and unloading, and the freight charges constitute a prohibitory expense under existing conditions. The freight charge of 1 cent per ton per mile, added to the cost of the material and the labor, makes the use of distant material rather a remote practicability unless some plan of transportation can be evolved that will be of benefit to both the operator and the transportation company.

It must be borne in mind that most of the railroads traversing the anthracite region depend upon the coal trade to furnish from 20 to 70 per cent of their total freight tonnage, and perhaps it may yet be possible for them to devise favorable freight rates for filling material. It is recognized that the problem of freight rates is far-reaching and must be approached advisedly; however, until some equitable method of dividing the expense can be worked out, mine filling involving long transportation of the filler will not be popular.

COST OF INTERMEDIATE TRANSPORTATION.

Intermediate transportation commences at the point where surface transportation ends. The crudest and cheapest mode of intermediate transportation is introducing the filler, without pipe, through crop falls, cave holes, or abandoned shafts. Practically the only cost connected with this method is that of preventing the blocking of openings with filler or of preventing the caving of the side walls.

A more efficient, and consequently more expensive, method is to introduce the filler by means of pipes, either in shafts or slopes. This entails the cost of a pipe line and its maintenance. Generally speaking, the lines consist of wood-lined cast-iron pipe, with flange or bell-and-spigot connections, or wood-stave pipe; the cost of handling filler with either kind of pipe is about the same, varying from one-fourth to one-half cent per cubic yard of filler passed through. Each type offers desirable advantages; the metal pipe possesses greater

strength to withstand shocks by roof falls or runaway cars, and the wood pipe possesses the advantage of being in shorter and lighter lengths. Metal pipe is seriously attacked by acid water, whereas wood pipe is practically immune from such attack.

Bore-hole transportation is generally employed where the mouths of slopes or shafts or other mine openings are above the drainage level; that is, the elevation of the railroad tracks at the loading chutes. It is by far the least expensive method, the cost varying from one-tenth to two-tenths of a cent per cubic yard.

COST OF UNDERGROUND TRANSPORTATION.

Underground transportation may for convenience be divided into three classes: (1) That in which the filler is allowed to flow unconfined; (2) that in which troughs are used; and (3) that in which pipes are used.

The cost of unconfined flow is practically negligible. The cost of trough transportation varies from one-tenth of a cent per cubic yard for wood troughs to three-tenths of a cent for metal troughs. The cost of pipe transportation per unit of 500 feet varies approximately as follows:

Kind of pipe.	Cost per cubic yard, cents.
Steel -----	0.30 to 0.35
Wood -----	0.35 to 0.40
Cast-iron -----	0.35 to 0.40
Wrought-iron -----	0.40 to 0.45

The physical and chemical properties of the various types of pipe, together with the conditions to be met, must determine which type will be the most economical for installation in a given mine.

COST OF DISTRIBUTION.

DISTRIBUTION ON THE SURFACE.

Distributing the filler on the surface entails the cost of conveying the material to a point where it will flow by gravity, of controlling the flow, and of depositing the filler at or near the bulkheads or retaining walls. The cost of handling, as stated under the heading "Surface Transportation," varies from 4 to 7 cents per cubic yard; to this must be added 1 to 1½ cents per cubic yard for flow control, and from five-tenths to seven-tenths of a cent per cubic yard for bulkhead construction; this aggregates a cost for surface distribution varying from 5½ to 9 cents per cubic yard.

DISTRIBUTION IN FLAT WORKINGS.

The cost of distribution in flat workings includes attendance and bulkhead construction. The cost of attendance varies from 1 to 1½ cents per cubic yard of filler and the cost of bulkhead construction from 6¼ to 7½ cents per cubic yard.

DISTRIBUTION IN CHUTE WORKINGS.

The cost of distributing filler in chute workings varies from $1\frac{1}{4}$ to $1\frac{3}{4}$ cents per cubic yard for attendance and from 11 to $12\frac{3}{4}$ cents per cubic yard for constructing bulkheads for individual filling. The cost when the panel or the collective system is used is considerably less.

DISTRIBUTION IN PITCH WORKINGS.

The cost of distributing filler in pitch workings varies from 1 to $1\frac{1}{2}$ cents per cubic yard for attendance and from 13 to 26 cents per cubic yard for bulkheads, depending on the type of bulkheads constructed and the system of filling employed. The cost for the panel or the collective system is considerably less than for the individual system.

COST OF DRAINAGE AND VENTILATION.

The cost of drainage and ventilation in connection with hydraulic mine filling is difficult to determine on account of the great variety of possible contingencies. The item of controlling the drainage water from the bulkhead to the sump is a simple matter in so far as maintaining the drainage pipes, troughs, or ditches, and constructing and cleaning the settling basins is concerned, the cost varying from one-fourth to one-half a cent per cubic yard handled. The cost of handling the water used for transporting the filler varies widely; if the usual pumping plant can easily handle the additional water, the cost is comparatively negligible, varying from 0.1 to 0.15 cent per cubic yard, but if additional pumping equipment, such as relay pumps, is required, the cost may vary from $1\frac{1}{4}$ to 8 cents per cubic yard of filler deposited. Under favorable geological conditions the drainage from several adjoining mines may be collected into a common sump and all the water lifted to the surface by high-duty pumps or by water hoists at considerably less cost than the figures quoted.

The cost of rearranging ventilation, if rearrangement is necessary, is practically negligible; if there is any appreciable cost it is overbalanced by the increased volume of air going into the working places and by the lessened frictional resistance so that the item may legitimately be charged to ventilation in the regular operating expense of the mine.

RECAPITULATION OF COSTS.

A recapitulation of the costs of hydraulic mine filling is given in the table following.

For surface filling, the cost of depositing breaker refuse, culm, or ashes, varies from 5 to 9 cents per cubic yard.

Recapitulation of cost of hydraulic mine filling.^a

Material.	Surface transportation.			Intermediate transportation.		Underground transportation.		Distribution.			Drainage.		Total.	
	Gravity.	Mechanical means.		Shaft or slope.	Bore hole.	Trough.	Pipe.	In flat workings.	In chute workings.	In pitch workings.	Incidental.	Special.	Minimum.	Maximum.
		Scraper or conveyor.	Pump.											
Culm.....	1-1½ 4-5½	4½-6 7½-10	2½-4 5½-8	1-1½ 2-1½	1½-2 1½-1½									
Culm mined with crushed breaker and boiler refuse.						1-2	1½-1½	7-9	12-14½	14-27½	1½-1½	1½-8	9½	56½
Local hydraulicked sand, loam, gravel, clay, etc.	8-14	11½-18½	9½-16½	1½-1½	1½-1½									
Local crushed sand, loam, gravel, clay, etc.	30-40			1-1½	1½-1½									
Material brought from a distance in returning empty coal cars.	The cost of the material, loading, freight, unloading, preparing and surface transportation.			1-1½	1½-1½	25 per cent should be added to each cost specified above.								

^a The figures in this table represent cents per cubic yard and are based on data obtained from operating plants with a capacity of at least 400 cubic yards daily.

CONCLUSION.

In concluding this preliminary report it seems fitting to refer to the lack of publicity so far given in this country to the subject of hydraulic mine filling. Although it has engaged the attention of mining men for many years, comparatively little has been published in this country concerning practical results. The contrary is true in Europe, especially as regards the application of the process in Upper Silesia. Engineers from that Province visited this country in 1893, gathered considerable information, and introduced the practice in Germany. Many articles regarding application, cost, and advantages of the process have appeared in foreign periodicals.

It is hoped that the investigations conducted by the city of Scranton^a and by the Pennsylvania State Anthracite Mine Cave Commission, appointed by Gov. Tener in 1911, and the scientific inquiries of the Bureau of Mines will be productive of results that will offer relief to anxious owners of the surface overlying mine workings, and to owners of industrial plants located in districts where subsidence may occur. These investigations should also prove of much service in aiding to lessen waste in the mining of valuable minerals other than anthracite.

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